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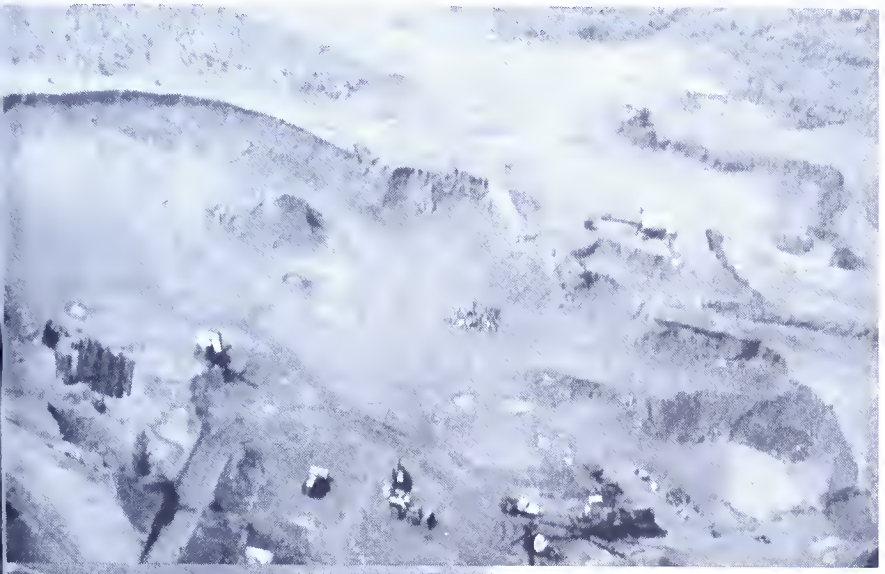
QUALITY OF GRAVEL RESOURCES IN NORTHWESTERN PENNSYLVANIA



Jesse L. Craft

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DEPARTMENT OF ENVIRONMENTAL RESOURCES
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TOPOGRAPHIC AND GEOLOGIC SURVEY
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Information Circular 86

QUALITY OF GRAVEL RESOURCES IN NORTHWESTERN PENNSYLVANIA

by Jesse L. Craft
Pennsylvania Geological Survey

PENNSYLVANIA GEOLOGICAL SURVEY
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PREFACE

Gravel is an enigmatic mineral resource. Its occurrence is widespread, yet good-quality usable gravel is quite limited in occurrence. Its price per unit is low, yet its importance in our society and our economy is great. We must have gravel to construct highways, bridges, dams, factories, homes, offices, etc. Gravel is vital to urban development, as it is to rural activities. Of gravel it can truly be said, it doesn't get the respect it deserves.

This report is designed to help locate additional supplies of quality gravel in a region where the availability of this essential resource is becoming more and more of a problem. Furthermore, the procedures and findings reported on here will be of significant benefit to gravel exploration throughout the northern areas of Pennsylvania and adjoining states.

ARTHUR A. SOCOLOW

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QUALITY OF GRAVEL RESOURCES IN NORTHWESTERN PENNSYLVANIA

by
Jesse L. Craft

ABSTRACT

Studies of the lithologic composition of various gravel deposits and the resistance of these lithologies to freeze-thaw breakdown have resulted in an understanding of the characteristics needed to evaluate undeveloped quality gravel resources.

Freeze-thaw testing has shown that weathered rock fragments are more susceptible to breakdown by disaggregation and splitting. Unweathered material tends to split along lamination planes and crushing-induced fractures. The total amount of physical breakdown is much greater in the weathered material than in the unweathered material.

The key to developing quality aggregate from natural gravel is the removal of the weathered material prior to crushing. In some cases, it may be necessary to remove other gravel components before crushing by designing special apparatus to remove specific rock fragments in order to reduce the total amount of breakdown during the freeze-thaw test.

The important characteristics to evaluate are: depth of weathering, total workable thickness of the deposit, size of the deposit, size of the particles making up the deposit, and lithologic composition. Size of the individual particles is very important inasmuch as one needs cobble-size particles to obtain a proper crush count in the large size fraction of the finished product.

Outwash valley-train deposits have the greatest potential for development because they are composed of coarse material, cover a relatively large area, and in many cases are quite thick. Ice-contact kames are excellent sources of gravel where the deposit is made up of cobble-size material.

The controlling factor affecting the suitability of any gravel deposit for development of an aggregate resource is whether the deposit is thick enough and large enough to have adequate unweathered gravel to make the deposit economically workable.

INTRODUCTION

One of the important items that must be taken into consideration in planning for economic growth and development in any area is the availability and cost of construction aggregate. Aggregate that can be used in concrete

to form floors, walls, and roads, or used as fill to level ground, makes up one of the larger components of construction costs.

In Pennsylvania there are three sources of construction aggregate: (1) natural sand and gravel obtained from deposits left by continental glaciers and distributed away from the glacial margin by meltwater streams; (2) crushed stone obtained by quarrying suitable bedrock; and (3) furnace slag from steel mills.

Each source of aggregate has its favorable and unfavorable aspects as well as its own special uses. The main controlling factors in the utilization of these materials in construction are: availability and quality of material, cost of production, and cost of transportation.

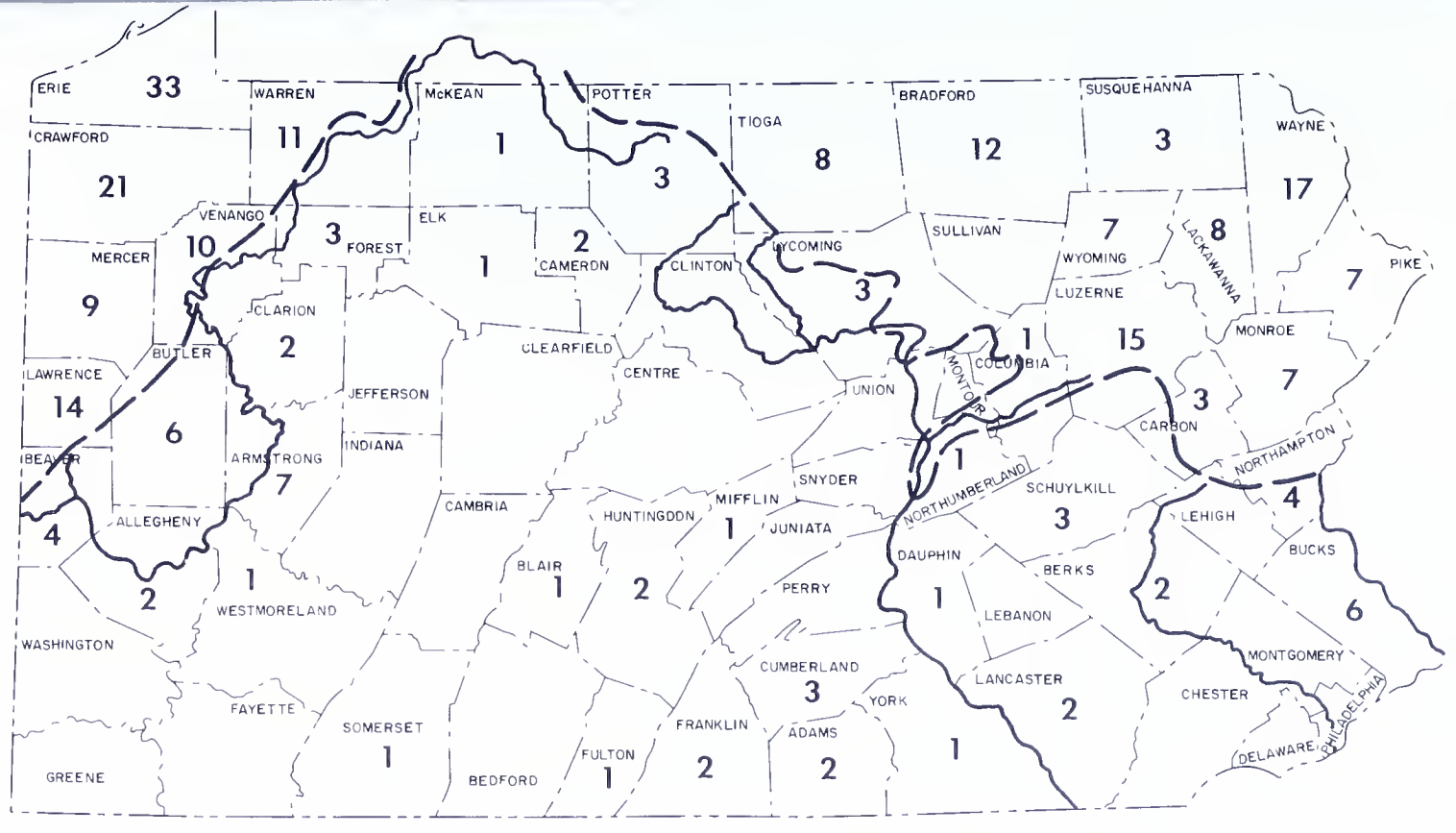
In general, construction aggregate is used within 30 miles of the aggregate production source. Where transportation costs are low, material can be hauled greater distances. For example, quality aggregate has been brought into Erie from Michigan because of the low cost of using lake freighters to deliver large volumes of aggregate.

This report deals only with the problems of natural aggregates of northwestern Pennsylvania. Figure 1 gives the number of known working sand and gravel pits in Pennsylvania in 1976 by county. The lithologic composition of the gravel deposits throughout the study area is quite similar. The bulk of the deposits is composed of fragments of local resistant bedrock. Material transported from a distant source is present in all samples studied, being more common in *ice-contact* deposits than in *glaciofluvial* deposits. This seems to be true regardless of the age of the deposit. In theory, therefore, all of the gravels deposited should be capable of producing quality material.

This, however, is not the case. Historically, quality gravel has been produced from the *kame* deposits in Crawford County and from the river dredge operation in Venango, Forest, and Warren Counties. Attempts at producing quality gravel from the *outwash* and *valley-train* terraces have generally been unsuccessful.

The purpose of this study is to take a careful look at the gravel to determine which rock types in the gravel fail the tests and to evaluate how this material can be processed to produce quality aggregate to meet the needs of the region. Experience has shown that the major test in determining aggregate quality is the freeze-thaw test. This test is designed to determine the ability of the aggregate to resist destruction by natural freeze-thaw cycles occurring during the winter months. Generally it has been found that any aggregate that stands up well to the freeze-thaw test will pass the other tests associated with determination of aggregate quality. Therefore, resistance to freeze-thaw breakdown was chosen as the parameter of study.

Sand and gravel ranked third in quantity and value of mineral commodities produced in Pennsylvania in 1975 (Table 1). Interestingly enough, the total volume of sand and gravel produced in Pennsylvania has been fairly



Major stream containing outwash from glacial margin

Approximate glacial boundary

Figure 1. Map showing the number of active sand and gravel pits by county in 1976. There was a total of 253 pits owned by 218 operators geographically distributed as follows: 130 in the northwest, 94 in the northeast and 29 in the southeast and south-central parts of the Commonwealth.

Table 1. *Mineral Production of the Top Three Commodities in Pennsylvania in 1975*

	Quantity (thousand short tons)		Value (thousands of dollars)	Value ($/ton)
1. Coal, strip and deep mine		90,340	2,309,508	29.62
2. Stone (total quarried)		60,177	149,670	2.49
a. Road aggregate	39,716		98,782	
b. Cement	8,424 to produce	6,172	20,953	29.62
Fluxstone	3,610		8,980	
c. Lime	4,212 to produce	1,940	10,476	30.95
d. Agriculture	1,204		2,993	
e. Other	4,212		10,476	
Total stone quarried for construction use	52,352		130,211	
3. Sand and gravel		17,401	48,742	2.80

constant (Table 2) during the last 10 years. The low production years were 1967 and 1975; production in each of these years was 17.4 million short tons. The biggest production year was 1971, when 22.6 million short tons was produced. The price of sand and gravel has steadily increased over the years (Table 3) from an average of $1.56 per ton in 1967 to $2.80 per ton in 1975. The jump in price in 1975 is much greater than the annual inflation rate and is primarily related to the increase in cost of operation associated with the closing of river dredge operations in the Allegheny River.

The importance of sand and gravel to the growth and development of an area is often overlooked. This is especially true in regions where deposits have been readily available for exploitation. However, these deposits are a non-renewable resource and once the material is removed, new deposits have to be found and developed.

Large volumes of aggregate are required in construction. For example, a recently finished section of the Allegheny Valley Expressway near Pittsburgh, only 2.19 miles long, used approximately 32,000 tons of Class "A" aggregate (Table 12) for concrete paving and structures, and 200,000 tons of Class "C" (Table 12) or better aggregate for subbase and shoulders. The 25-mile total length of this road will require between 2.75 and 3 million tons of Class "C" or better aggregate. To place this in visual terms, this amount of aggregate would require a workable gravel deposit 1,000 feet long, 1,000 feet wide, and 100 feet deep, assuming no waste of any kind.

Historically in northwestern Pennsylvania, the Allegheny and Ohio Rivers have been the major source of quality aggregate. Gravel has been commercially produced from the riverbed since the mid-1800's. In the early days riverboat captains would push empty barges up the river during flood stage of the river as far as Franklin, Venango County, and ground them on a sand bar. Families would live on the barges (Figure 2), and during low water time they would fill the barge with cobble-size stones. Once the barges were full, the riverboat captain would be notified. During the next high-water phase of the river, the barge would be picked up and taken down the river. Many of the early streets of Pittsburgh were paved with cobblestones obtained in this manner. When mechanized digging and crushing equipment was developed and a demand for cheap construction aggregate arose, operators started digging up the gravel bars of the rivers. Floating diggers were finally developed, and river dredge operations became a major source of aggregate along the Allegheny River from Warren to Pittsburgh.

In the early 1970's concern for the environment and efforts by state and federal agencies to improve and protect the water quality of major rivers brought considerable pressure against dredge operations. In 1972 there were five dredges operating in the upper Allegheny River: one each at Franklin, Tionesta, and Tidioute, and two at Warren. These five dredges supplied over 85 percent of the aggregate used throughout the region and almost all

Table 2. *Sand and Gravel Sold or Used by Producers, by Classes of Operations and Uses*[1]

(Quantities in thousands of short tons; values in thousands of dollars)

Class of operation and use	*1967*			*1968*			*1969*			*1970*			*1971*		
	Quantity	*Value*	*$/Ton*	*Quantity*	*Value*	*$/Ton*	*Quantity*	*Value*	*$/Ton*	*Quantity*	*Value*	*$/Ton*	*Quantity*	*Value*	*$/Ton*
Commercial operations:															
Sand:															
Building	4,855	7,424	1.53	5,420	8,296	1.53	5,094	7,811	1.53	4,700	7,749	1.65	4,651	8,352	1.80
Paving	3,678	5,636	1.53	3,433	5,343	1.56	3,443	5,473	1.59	3,158	5,088	1.61	2,678	4,700	1.76
Fill	24	20	.83	28	38	1.36	89	138	1.55	85	113	1.33	135	250	1.85
Undistributed[2]	1,520	5,020	3.30	1,505	5,317	3.36	1,859	5,921	3.19	2,466	7,015	2.85	3,211	7,727	2.41
TOTAL	10,077	18,100	1.80	10,386	18,994	1.83[3]	10,487[3]	19,342[3]	1.84	10,409	19,965	1.92	10,675	21,029	1.97
Gravel:															
Building	2,562	4,141	1.62	3,599	5,921	1.65	3,630	5,900	1.63	3,501	5,897	1.68	4,330	6,874	1.59
Paving	4,147	6,639	1.60	3,367	5,324	1.58	3,476	5,714	1.64	3,531	6,523	1.85	2,994	6,141	2.05
Fill	343	214	.62	373	214	.57	320	227	.69	935	1,335	1.43	768	1,001	1.30
Undistributed[4]	298	441	1.56	286	386	1.35	183	266	1.45	127	195	1.54	3,896	7,259	1.86
TOTAL	7,350	11,435	1.56	7,625	11,845	1.55	7,619	12,108[3]	1.59	8,094	13,950	1.72	11,988	21,275	1.68
TOTAL SAND AND GRAVEL	17,427	29,535	1.56	18,011	30,839	1.71[3]	18,105[2]	31,451[3]	1.74	18,503	33,915	1.83	22,663	42,304	1.84

Class of operation and use	1972			1973			1974			1975		
	Quantity	Value	$/Ton	Quantity	Value	$/Ton	Quantity	Value	$/Ton	Quantity	Value	$/Ton
Commercial operations:												
Sand:												
Building	5,164	9,265	1.79	5,366	10,747	2.00	Figures not available			Figures not available		
Paving	2,441	4,649	1.91	3,625	7,293	2.01	Figures not available			Figures not available		
Fill	100	129	1.29	123	182	1.48	Figures not available			Figures not available		
Undistributed[2]	3,384	8,247	2.44	3,386	8,840	2.61	Figures not available			Figures not available		
TOTAL	11,089	22,290	2.01	12,500	27,062	2.17	10,048	27,430	2.73	9,500	28,231	2.97
Gravel:												
Building	3,992	7,389	1.85	4,520	8,862	1.96	8,271[5]	19,104	2.31	7,219[5]	19,432	2.67
Paving	2,866	5,940	2.07	2,718	5,790	2.13	5,925[5]	14,788	2.50	6,279[5]	17,023	2.71
Fill	340	301	.89	462	463	1.00	2,337[5]	3,876	1.66	2,305[5]	4,430	1.92
Undistributed[4]	469	884	1.89	377	653	1.73	1,538[5]	7,413	4.82	1,600[5]	7,856	4.91
TOTAL	7,667	14,514	1.89	8,077	15,768	1.95	8,023	17,751	2.21	7,930	20,509	2.58
TOTAL SAND AND GRAVEL	18,756	36,804	1.89	20,577	42,830	2.08	18,071	45,181	2.50	17,403	48,741	2.80

[1] Data are from the following reports published by the Pennsylvania Geological Survey: Yeloushan, C.C. (1969), *The mineral industry of Pennsylvania in 1967*, Information Circular 63; Yeloushan, C. C. (1970), *The mineral industry of Pennsylvania in 1968*, Information Circular 69; Leaf, C. G. (1971), *The mineral industry of Pennsylvania in 1969*, Information Circular 71; Cooper, F. D. (1972), *The mineral industry of Pennsylvania in 1970*, Information Circular 73; Cooper, F. D. (1974), *The mineral industry of Pennsylvania in 1971*; Cooper, F. D. (1975), *The mineral industry of Pennsylvania in 1972*; Cooper, F. D. (1976), *The mineral industry of Pennsylvania in 1973*, Information Circular 81; Kebblish, W. F. (1978), *The mineral industry of Pennsylvania in 1974*, Information Circular 82; Kebblish, W. F. (1979), *The mineral industry of Pennsylvania in 1975*, Information Circular 85.

[2] Includes blast, engine, filtration, fire and furnace, foundry, glass, grinding and polishing, molding, oil (hydrafrac), abrasives, chemical, enamel, filler, pottery, and other uses.

[3] Data may not add to totals shown because of independent rounding.

[4] Includes railroad ballast.

[5] Includes sand production.

Table 3. *Local Price per Ton of Class A Gravel, 1967-1976, in Northwestern Pennsylvania, As Supplied by Two Operators*

		1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Operator 1	Gravel	$1.70	$1.66	$1.91	$2.05	$2.08	$2.15	$2.13	$2.45	$3.00	$3.09
Operator 2	Gravel	$1.95	$2.15	$2.33	$2.40	$2.60	$2.70	$2.80	$3.00	$4.25	$4.25

Figure 2. Paddle wheeler pushing an empty gravel barge in the upper Allegheny River circa 1860. Huts on the barges are the family living quarters (photograph from the collection of Bill Smith, Oil City, Pennsylvania).

of the quality aggregate for highway-wearing surfaces constructed by the Pennsylvania Department of Transportation. Pressure from environmental groups and new water-quality laws in Pennsylvania have forced all of the dredge operations out of the upper Allegheny River.

Dredge operators for years have been searching for sand and gravel deposits away from the river and closer to the users to reduce transportation costs. They have located numerous deposits, but only a few of these deposits have been able to supply aggregate to meet PennDOT (Pennsylvania Department of Transportation) and other construction specifications. Those deposits that are capable of supplying material that meets the quality-control specifications are difficult to work and limited in size, and they are rapidly depleted.

The problem is not simply one of locating gravel deposits; it is one of finding deposits that will be large enough to meet the economic requirements of pit development and, after processing, meet PennDOT quality requirements.

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GRAVEL SPECIFICATIONS

The different uses that can be made of sand and gravel by the construction industry are controlled by specifications as to aggregate quality and size gradation. The term quality refers to the response of the aggregate to a series of laboratory tests. The tests cover: freeze-thaw, Los Angeles rattler test, elongate pieces, loss by washing, crushed fragments, and common deleterious substances.

One of the largest users of construction aggregate in Pennsylvania is the Department of Transportation. This organization has established specific quality and grade-size standards for use in the different phases of highway construction. Materials meeting the specifications of the Pennsylvania Department of Transportation are also called for in the specifications of a number of local governments for roads and streets, for structural concrete by the General State Authority, and by a large number of private architectural and engineering firms. The grading and quality requirements for aggregate specified by PennDOT are shown in Tables 4 and 5. Sand is not included in this report, so grading and quality requirements for it have been excluded from these tables.

The Pennsylvania Department of Transportation subdivides aggregate quality into three main categories—A, B, and C—on the basis of the laboratory test for quality, and assigns a number prefix to designate the grade-size distribution of the aggregate. Type A material is the highest quality of material and is required for all concrete and surface courses in bituminous paved roads. Type A or B aggregates are required for bituminous base course and for crushed aggregate base course. Type C or better aggregate is required for subbase as well as some other types of base course.

SOURCES OF NATURAL GRAVEL

Throughout the history of exploitation of gravel resources in western Pennsylvania, very little thought was given by the pit operators to the origin

Table 4. *Size and Grading Requirements for Coarse Aggregate*

(Based on laboratory sieve tests, square openings)

PA nos.	Total percent passing												
	4″	3-1/2″	2-1/2″	2″	1-1/2″	1″	3/4″	1/2″	3/8″	#4	#8	#16	#10
4	100	90-100	35-70		0-15		0-5						
3A			100	90-100	35-70	0-15		0-5					
2B					100	90-100		25-60		0-10	0-5		
2A							52-100		36-70	24-50	16-38*	10-30	2-1
2RC					100					15-60			
2						100	90-100		20-55	0-10	0-5		
1B								100	75-100	10-30	0-10		
1									100	75-100			10-3
1NS						100		90-100		0-15			
2NS					100	90-100		0-15					

*Applies only for bituminous mixtures.

Note: A combination of no. 1NS and no. 2NS may be substituted for no. 2B provided that not more than 50 percent or less than 30 percent of the combination is no. 1NS size.

Reference: Pennsylvania Department of Transportation (1970), *Specifications — Form 408*, p. 537-542.

Table 5. *Physical Requirements for Coarse Aggregate*

		Type A	Type B	Type C
(1)	Sodium sulfate test — maximum % loss at 5 cycles by weight. AASHO Designation T 104 (except pans were used instead of sieves)	12	12	20
	Los Angeles Rattler test — maximum AASHO Designation T 96. Percentage loss by weight at 500 revolutions A, B, and C gradings	35	45	55
(2)	Thin and elongated pieces, % by weight — maximum	10	10	—
(3)	Loss by washing, % by weight — maximum PTM no. 100	1	1	12
(4)	Crushed fragments, minimum % by weight — individual and combined sizes	*55	50	50
(5)	Common deleterious substances:			
	Soft fragments, % by weight (maximum)	2	2	10
	Shale, % by weight (maximum)	1	1	10
	Clay lumps, % by weight (maximum)	0.25	0.25	3
	Coal or coke, % by weight (maximum)	1	1	5

Note: The sum of percentages of all common deleterious or objectionable substances, exclusive of glassy particles and iron, shall not exceed 2% for Type A, 3% for Type B, and 15% for Type C.

*Aggregate for use in any Bituminous Surface Course, or any allied surface operation, shall have a minimum of 85% crushed particles having at least two faces that resulted from fracture.

Reference: Pennsylvania Department of Transportation (1970), *Specifications — Form 408*, p. 537-542.

of the deposits. The standard exploration method was to travel around the countryside looking for farm pits. If it appeared that there was a sufficient quantity of gravel to promise an economic operation, a lease would be negotiated and a test pit excavated using a back hoe. A truckload of gravel would then be hauled to a nearby crusher plant and processed. Samples from this crusher run would be sent to a laboratory for quality testing. If the material passed the test, the pit would be developed. If it did not pass the test, nothing more was done. No consideration was given to the origin of the deposit or why the material failed the test as aids to exploration for additional deposits.

Early field work in the area by the author indicated that some of the deposits tested and rejected by gravel operators contained abundant solid material having the same characteristics as the acceptable river dredge deposits. The question, then, was why the material obtained from the rejected test pit failed the test.

During discussion of the problem with gravel operators of the region, it became obvious that there are two major factors involved in producing quality aggregate in this area. The first and foremost is the gravel resource itself, and the second is the method of operation and maintenance of the pit and crushing equipment.

The primary source of natural sand and gravel in Pennsylvania is unconsolidated deposits associated with the advance and retreat of the continental glacier that once covered most of northwestern and northeastern Pennsylvania (Figure 1). These massive ice sheets were many thousands of feet thick. They originated to the northeast in Canada and, over a period of thousands of years, advanced southward, terminating in the United States. The effects of this glaciation upon Pennsylvania were great. Rivers were diverted from old courses into new channels, and topography was altered by the smoothing effect of erosion and the deposition of sediment from the ice mass. Outside the area of glaciation new stream channels were cut and old valleys were deepened by the erosive action of meltwater draining from the glacier front.

The unconsolidated deposits associated with glaciation are divisible into two main groups on the basis of being deposited either by the glacier or by the meltwater from the glacier.

Material deposited directly by the ice is poorly sorted to unsorted and is called unstratified drift or till by the glacial geologist. If the material was deposited by the bottom of the ice sheet as it advanced over the land, it is called *lodgment till*. If the material had been incorporated into the ice mass and then was deposited as the ice melted away, it is referred to as *englacial till*; and if it was carried on top of the ice and reworked somewhat by wind and water action before and during deposition, it is referred to as *ablation till*. Tills are generally unsuitable for construction use because of the compactness of the deposit and the high clay content.

Material that had been transported from the ice mass by wind or running water was sorted, and finer sizes of particles were removed and coarser ones left behind. This water-transported material was deposited in layers and is referred to as *stratified drift*. Specific names applied to stratified-drift deposits are related to the predominant size of the particles making up the deposit, i.e., clay, silt, sand, or gravel.

A second method of describing deposits left by the glacier is related to the origin of the deposit. Figures 3 and 4 show the different types of deposits and how they were formed. In general, deposits are classified by origin because they have definite topographic expressions that enable the geologist to recognize the depositional environment of the deposit. There are three major subdivisions of depositional environment to consider: the materials deposited directly by the ice; the materials deposited on, within, or adjacent to the ice by running water; and the materials deposited by running water away from the ice.

The deposits left directly by the ice form a very rough, irregular surface and are referred to as *moraines*. If the deposits are formed by the general melting of the ice sheet, a bumpy, blanketlike deposit will be laid down on the surface and is referred to as *ground moraine*. This deposit will consist

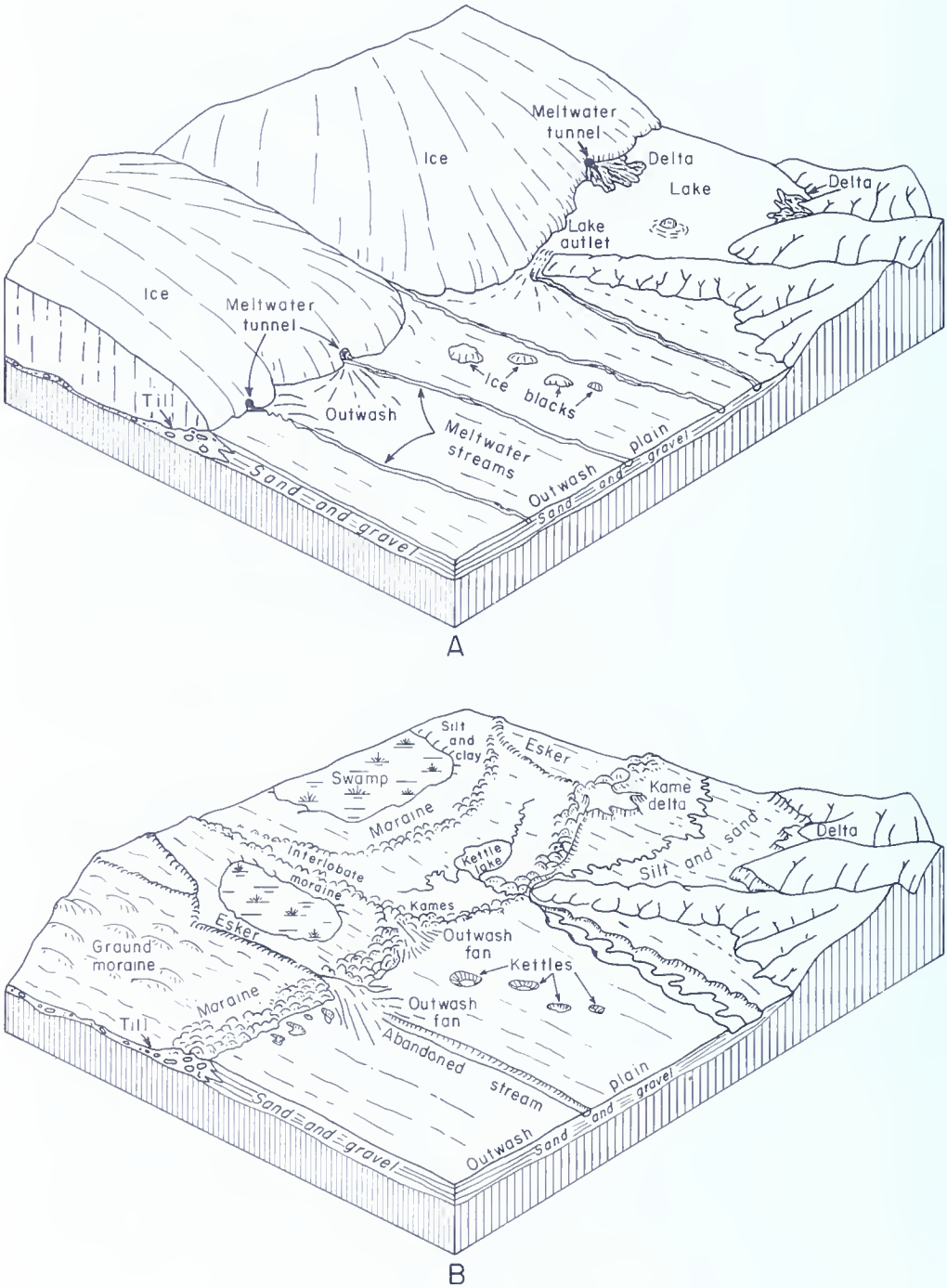
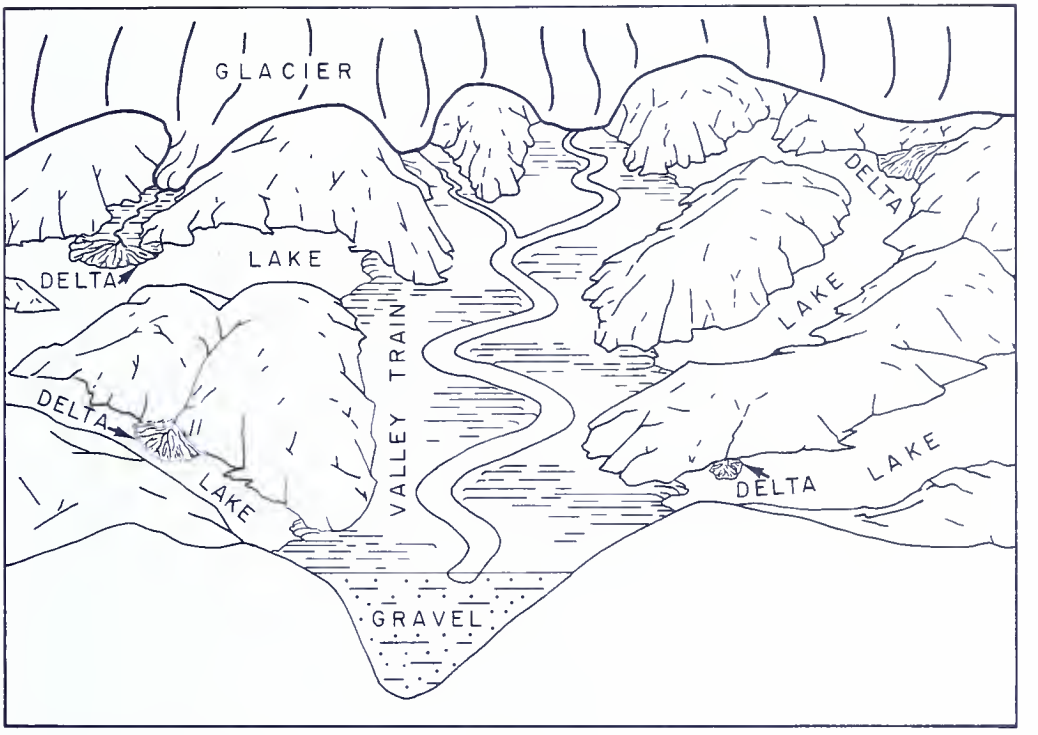
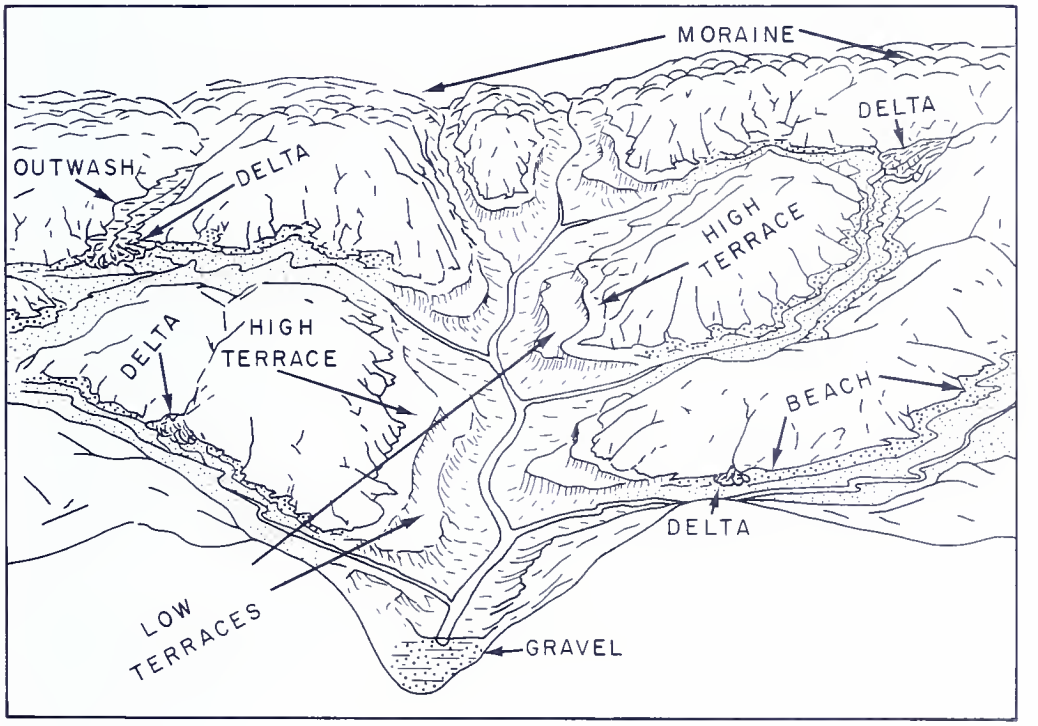


Figure 3. Landforms produced near the margin of an ice sheet in relatively flat terrain. (A) an ice margin in nearly stagnant condition; (B) subglacial forms revealed after the ice is completely gone. (Drawings modified from Strahler, A. N. (1971), The earth sciences, New York, Harper and Row, p. 722.)



A



B

Figure 4. Landforms produced near the margin of an ice sheet that is advancing and stagnating in a hilly terrain. (A) during glaciation; (B) after the ice has melted. (Drawings by Patricia Book, 1978.)

mainly of till having some small stratified-drift deposits scattered on top. These stratified-drift deposits are generally too small to be developed as a commercial operation.

If the material has been deposited at the edge of the ice mass a pronounced pile of debris will develop. The resulting very irregular ridgelike form is referred to as a *terminal* or *end moraine* if at the outermost position of the advance, or a *recessional moraine* if behind the terminal moraine (Figure 3). If lobes of ice merge, the moraine formed by the edges of the two lobes are called *interlobate moraines.*

When material has been transported and deposited by running water on or against the glacier, it is called a *kame.* There are different types of kames, classified by their origin. For example, if the front edge of a glacier is buried beneath stratified drift when the ice melts away, it will leave a landform having the topographic expression of a moraine but will be composed mainly of stratified material. This type of deposit would be called a *kame moraine.* When the meltwater from the glacier flows from the ice mass into a lake, a *delta* will form from the deposition of material being transported by the running water into the standing water of the lake. Because one side of the delta is in contact with the ice mass, it is called a *kame delta.* Kame deposits are also commonly associated with interlobate moraines and are associated with deep valleys where ice has stagnated and becomes buried by stratified drift. When a buried ice block finally melts away, it will leave a depression in the topography called a *kettle.* Kame deposits are very good sources of gravel. They do, however, tend to be irregular in size and composition, which often makes the development of a commercial operation difficult.

When a meltwater tunnel develops in the glacier, rock fragments will be transported into the tunnel by the running water and deposited on the floor of the tunnel. After the ice has melted away, the deposits will remain as a ridge that marks the course of the subglacial river. The ridge is referred to as an *esker* and is composed of stratified drift, usually a very coarse gravel. Eskers are often covered by till deposited as the ice melts down over the esker. Kames and eskers are associated with a stagnant, melting ice mass.

When meltwater flows away from the ice mass, fragments in transport will be deposited and these deposits will have a topographic expression characteristic of their origin of deposition.

If the topography in front of the glacial margin has been smoothed and buried beneath stratified drift, it is called an *outwash plain.* If a valley has been filled with this outwash debris, it is referred to as *valley train* (Figure 4). When the outwash debris is carried into a lake, an *outwash delta* is formed. Sometimes a major valley will become filled with outwash to such an extent that smaller tributaries will become blocked and lakes will form. Outwash deltas will then be developed in these lakes from the main valley,

and normal deltas can develop in the lake from streams not associated with the glacier. Beach deposits will be formed in association with the lake surfaces.

When the glacier melts back from the moraine, the volume of sediment will decrease and erosion of the valley-train fill will commence. The lakes will drain into the main valley, accelerating the erosion. This erosion of the valley fill will leave remnants of the fill in the form of terraces, deltas, and beaches high up on hillsides adjacent to the valley.

FREEZE-THAW TEST

The standard testing procedure for freeze-thaw characteristics of aggregates is the use of a saturated solution of sodium sulfate. The sample is soaked in this solution overnight at a temperature of 20°C, then dried in an oven for 6 hours at 100°C. This wet-dry cycle is repeated five times. The growth of sodium sulfate crystals within the void space in the rock simulates the growth of ice crystals in the natural environment. This test is a very conservative one in that the crystallization forces generated by sodium sulfate are greater than those of ice.

Figure 5 is a flow chart of the procedure used in this study. The standard testing procedure has been modified slightly in that pebble-lithology studies were done before and after the sodium sulfate treatment. This modification in the procedure was necessary to establish what was happening to the different constituents of the gravel during the test.

GRAVEL COMPOSITION

The quality of any gravel deposit is determined by the types of rock that make up the deposit, their size distribution, and the depth of weathering of the deposit since its formation.

All of the gravel deposits of northwestern Pennsylvania are directly associated with the advance and retreat of the continental glacier. The rocks that make up the gravel deposits were first picked up and transported by the glacier. Then, as the ice melted away, these rock particles were released from the ice and transported by running water to a site of deposition. Because the rocks were picked up and transported by the moving glacier from various locations, one will find some material in the deposits that has been transported great distances. For example, there are no crystalline rock outcrops in western Pennsylvania; therefore, crystalline rock material in the deposits had to be transported from a different place. The nearest source of crystalline rock exposed on the surface where the advancing glacier could pick it up is located in eastern Ontario, Canada, in the vicinity of Kingston,

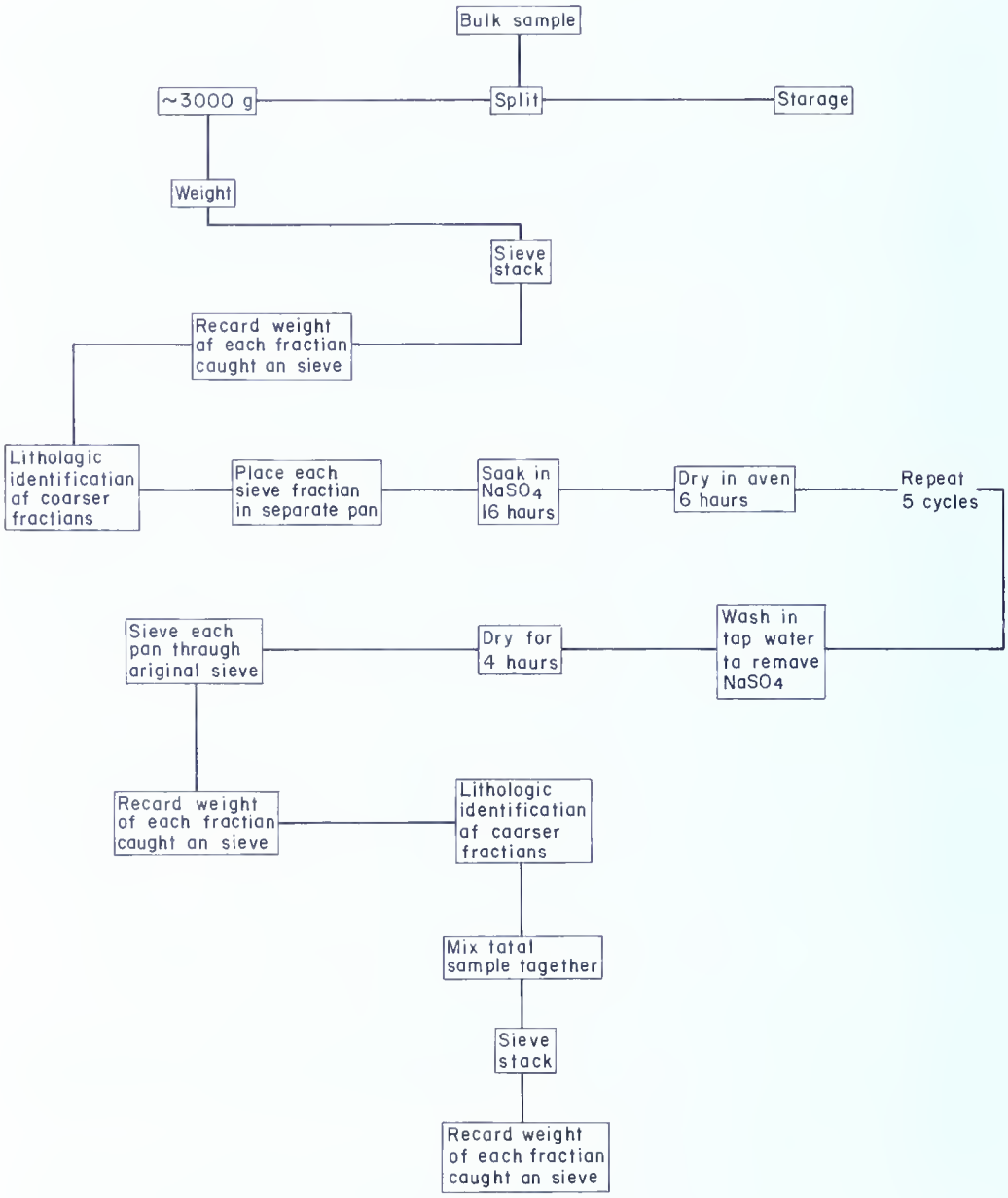

Bulk sample
~3000 g
Split
Storage
Weight
Sieve stack
Record weight af each fractian caught an sieve
Lithologic identificatian af coarser fractians
Place each sieve fractian in separate pan
Saak in NaSO4 16 haurs
Dry in aven 6 haurs
Repeat 5 cycles
Wash in tap water ta remave NaSO4
Dry for 4 haurs
Sieve each pan thraugh original sieve
Record weight of each fractian caught an sieve
Lithologic identificatian af caarser fractians
Mix tatal sample tagether
Sieve stack
Record weight of each fractian caught an sieve

Figure 5. Flow chart for the sodium sulfate test.

and in the Lake Ontario basin between Kingston, Ontario, and Toronto, Ontario. Therefore, crystalline material had to have originated at least as far away as that area, and could have come from even farther away.

Studies of ice-formed deposits (called "till") have demonstrated that 90 percent of the material moved by basal transport has traveled only 1 to 5 miles. Longer distance transport of rock fragments occurs where material has been carried up into the ice mass. Studies in glaciofluvial deposits have shown that 90 percent of this material has been transported 1 to 10 miles

from its source area. Long-distance transport of rock fragments by glacial ice and associated meltwater depends on the size, shape, specific gravity, and durability of the fragments. That local material dominates till composition is clearly shown by the lithology studies of the different gravel deposits. Tables 6 through 9 give the lithologic compositions of the gravel deposits studied in this project.

Figure 6 is a generalized geologic rock column for the area of the study. The surface bedrock of the area ranges in age from Late Devonian to Early Pennsylvanian. The rock composition of this sequence of strata is mainly shale (see Figure 7 for meaning of terms) containing interbedded siltstones and sandstones. There are no limestones, dolostones, or crystalline rocks at the surface in the study area. Therefore, the presence of these materials in a deposit is indicative of long-distance transport by the glacier prior to deposition in the gravel deposit.

A review of the pebble composition of the gravel deposits that were studied clearly shows the influence of local bedrock on the final composition of the deposit. More than 50 percent of all the deposits are composed of siltstone, which is the rock type in the stratigraphic section strong enough to withstand the crushing and grinding action of the ice after being picked up, and durable enough to withstand the impact effects of being transported by the meltwater coming from the glacier.

The origins of the deposits are also reflected to some degree in their compositions. The deposits around Conneaut Lake, Crawford County, have the highest percentage of material transported from distant sources, indicating an englacial transportation of the material, deposition near ice, and less dilution by local bedrock. These deposits have been identified, by other features, as kames that formed while the ice mass was melting away; at the time of deposition, rock fragments were washed off the high areas on the ice surface and deposited in low areas on the ice. This deposit was formed behind the ice front. Deposits formed at the ice front and in the valleys away from the ice margin will reflect more of the character of the local bedrock. Deposits close to the ice margin contain considerable amounts of shale fragments. These fine-grained fragments do not show up in the lithology studied because they break up very easily and are not preserved. As one goes further away from the ice front, shale fragments disappear due to abrasion and impact effects on the fragments during transportation by meltwater. Only the more resistant rock fragments from the local stratigraphic section are preserved in the deposits.

In general, the lithologic composition of the gravel deposits throughout the study area is quite similar. The bulk of the deposits is composed of resistant local bedrock material. Material transported from a distance is present in all samples studied, being more common in ice-contact type deposits than in meltwater-transported deposits. This seems to be true regardless of the

Table 6. *Lithologic Composition of Some Crawford County Kame Deposits*
(Numbers represent weight percents)

	Conneaut Lake Sand and Gravel, working face, by weight percent	Conneaut Lake Sand and Gravel, field count, working face, by pebble percent	Conneaut Lake Sand and Gravel, crush pile, by weight percent	Atlas Sand and Gravel, Hartstown, Crawford County, working face, by weight percent	Atlas Sand and Gravel, Hartstown, Crawford County, crush pile, by weight percent	Dunn Sand and Gravel, crush pile, by weight percent	Dunn Sand and Gravel, working face, by weight percent
Gray siltstone	30.0	29.3	28.0	33.3	45.5	48.3	- -
Gray calcareous siltstone	8.3	17.8	23.9	21.6	18.8	21.3	3.9
Brown siltstone	26.0	- -	- -	10.8	4.9	9.3	30.8
Brown calcareous siltstone	6.3	- -	3.8	26.3	- -	3.4	35.4
Crystalline rocks	18.1	7.7	12.2	15.7	6.6	10.7	4.6
Chert	19.6	3.3	4.0	6.4	2.2	4.4	16.1
Limestone	- -	32.6	28.0	2.9	18.5	1.7	9.1
Sandstone	- -	9.2	- -	- -	3.6	0.7	- -

Table 7. *Lithologic Composition of Some Gravel Deposits in the Titusville-Edinboro and Lake Pleasant Areas, Crawford and Erie Counties*

(Numbers represent weight percents)

	Hasbrouck Sand and Gravel, dragline	Hasbrouck Sand and Gravel, crush pile, no impactor	White City Sand and Gravel, working face	Borrow pit, Titusville North quad.	Gravel operation, near Lake Pleasant, Erie County, crush pile	North Edinboro, working face
Gray siltstone	35.7	38.9	59.8	69.0	38.1	53.8
Gray calcareous siltstone	17.8	13.9	– –	– –	28.3	– –
Brown siltstone	27.5	38.6	– –	16.0	0.9	40.8
Brown calcareous siltstone	5.6	– –	– –	– –	5.3	– –
Crystalline rocks	2.7	4.9	8.4	12.8	7.1	1.0
Chert	0.7	1.2	6.9	0.9	0.3	1.4
Limestone	6.6	– –	4.3	– –	18.4	0.7
Sandstone	1.6	2.5	20.9	– –	1.3	2.2

Table 8. *Lithologic Composition of Gravel Deposits, Warren County Area*

(Numbers represent weight percents)

	LAND BASE					RIVER				
	1674-1 Brokenstraw Sand and Gravel, unscreened	1674 Brokenstraw Sand and Gravel, sieved, crushed and washed	1574-A Emlenton Limestone, Pittsfield, crush pile includes weathered material	Emlenton Limestone, Pittsfield, lower 10' of working face	Tionesta Sand and Gravel, Garland Plant, crush pile	Warren River Dredge, crush pile	Warren River Dredge, crush pile	Warren River Dredge, crush pile, 1 year old	Warren River Dredge, barge	General Concrete, Warren, crush pile
Gray siltstone	51.3	60.0	15.7	70.8	53.8	50.2	46.3	7.1	49.9	36.2
Gray calcareous siltstone	13.4	16.8	3.3	4.3	11.7	28.3	18.6	2.3	5.4	7.9
Brown siltstone	17.3	9.4	77.5	– –	22.6	4.3	8.9	81.6	17.1	6.8
Brown calcareous siltstone	5.3	1.1	– –	10.3	– –	2.3	5.3	– –	5.6	– –
Crystalline rock	0.6	4.4	2.0	4.2	2.0	9.6	9.3	6.2	14.9	9.0
Chert	0.4	0.8	1.5	2.3	2.0	3.8	7.3	1.6	5.0	2.3
Limestone	11.7	4.2	– –	– –	3.9	– –	– –	– –	3.1	8.5
Sandstone	0.4	2.9	– –	8.1	3.8	1.5	2.7	7.0	– –	29.4

Table 9. *Lithologic Composition of Gravel Deposits, Franklin Area*

(Numbers represent weight percents)

	LAND BASE					RIVER	
	Fosters Corners, crush pile	Tionesta Sand and Gravel, Cooperstown, from below water processed through Class A plant	Tionesta Sand and Gravel, Cooperstown, sample collected from below clay cover in new part of working pit	Reno pit, sample collected from cemented knob in lower part of pit	Reno pit, sample collected from working face adjacent to cemented knob	Franklin Dredge, 2-B pile	Franklin Dredge, at dock side
Gray siltstone	2.5	48.8	2.8	39.2	26.8	25.8	34.3
Gray calcareous siltstone	– –	– –	12.3	1.5	– –	10.7	– –
Brown siltstone	92.0	7.1	34.7	15.5	– –	26.9	– –
Brown calcareous siltstone	– –	– –	9.6	– –	– –	0.2	–
Crystalline rock	7.1	3.3	5.4	13.5	14.6	12.0	15.3
Chert	4.8	1.5	7.1	13.3	– –	5.7	7.5
Limestone	– –	– –	6.9	1.5	– –	7.4	11.0
Sandstone	– –	39.1	4.7	19.6	58.6	11.5	31.9

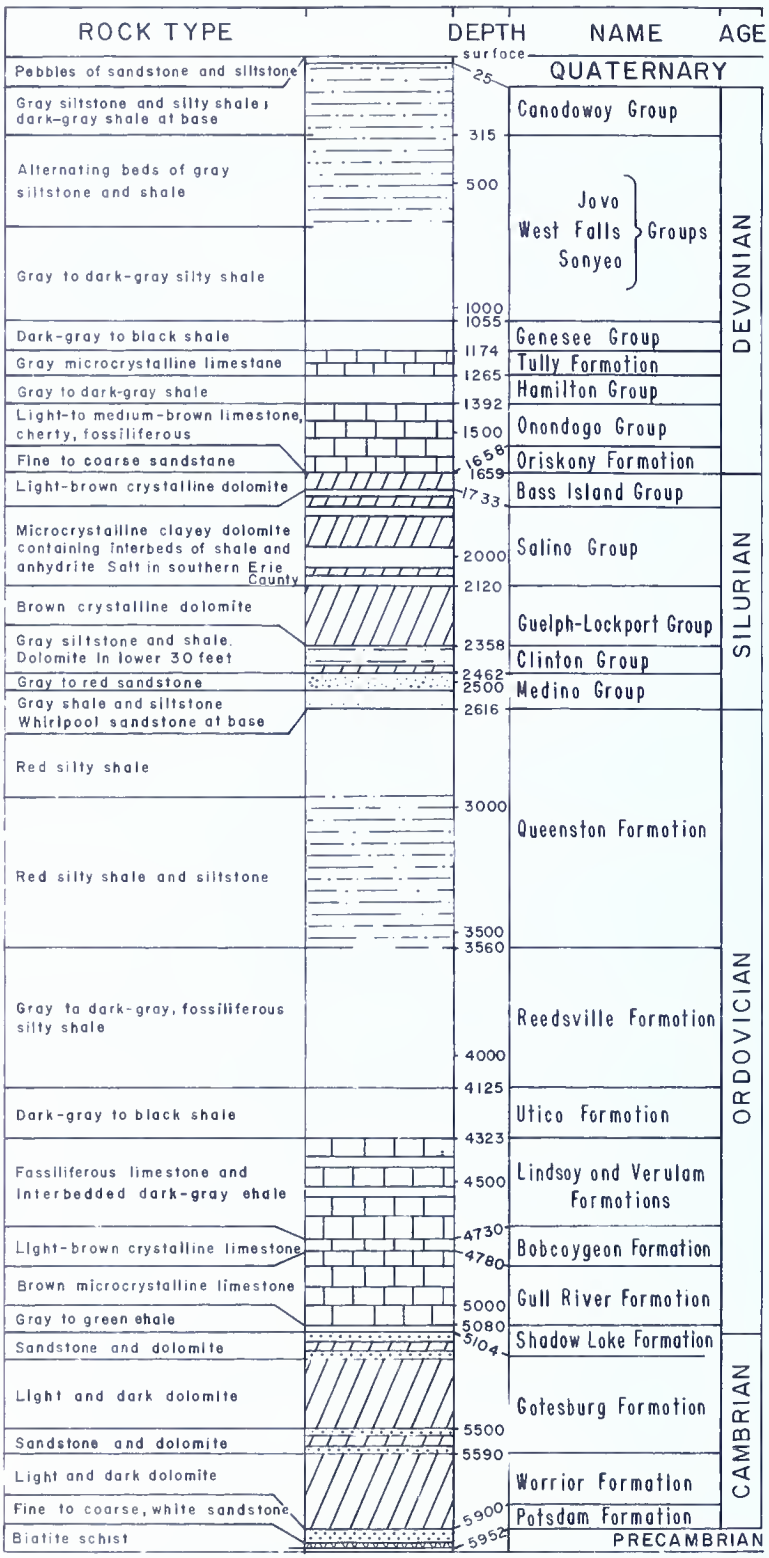


Figure 6. Generalized bedrock columns in the study area. The column at the right shows the rock exposed at the surface, and, therefore, in contact with the continental glacier. The column at the left shows the rock in the subsurface; these rocks are exposed at the surface to the north and east of the study area.

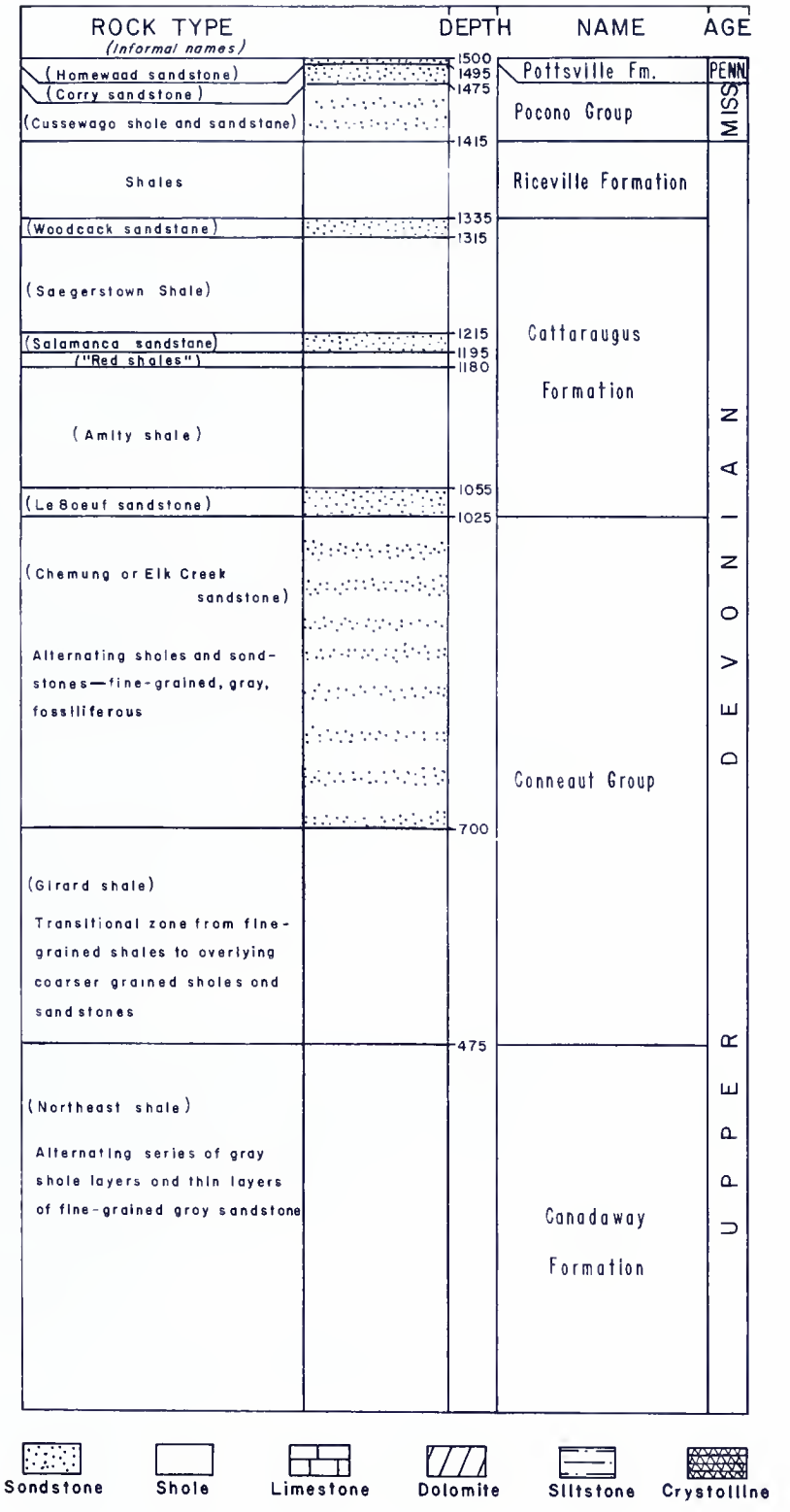


Figure 6. (Continued). Columns modified from Tomikel, J. C., and Shepps, V. C. (1967), The geography and geology of Erie County, Pennsylvania, Pennsylvania Geological Survey, 4th Ser., Information Circular 56, p. 24 and 28.

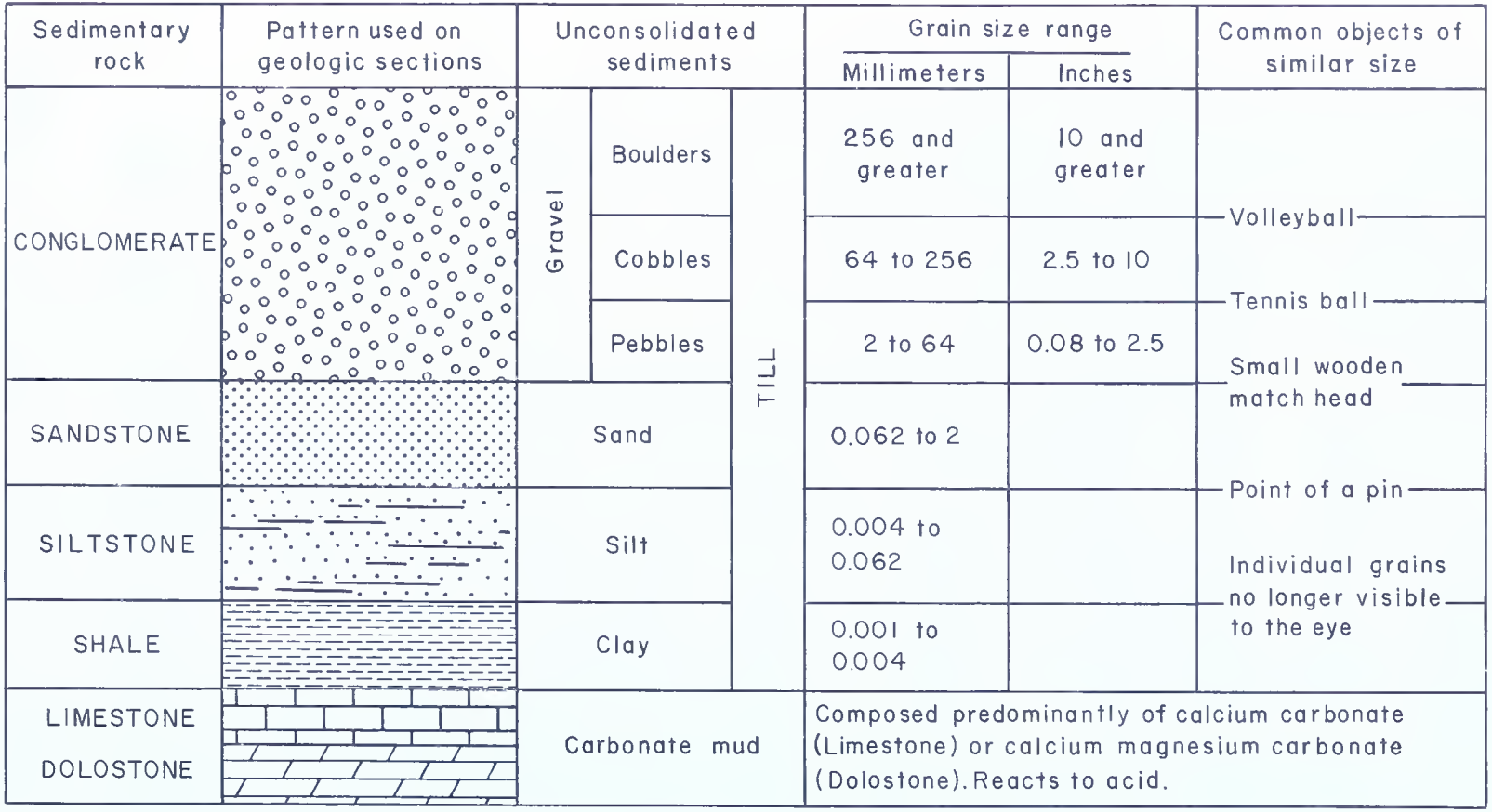


Figure 7. Classification of common sedimentary rocks and unconsolidated sediments, and their size ranges.

age of the deposit. In theory, therefore, all of the gravels in the area should be capable of producing quality aggregate.

This, however, is not the case. Historically, quality gravel has been produced only from the kame deposits in Crawford County and from the river dredge operations in Venango, Forest, and Warren Counties. Attempts at producing quality gravel from the outwash and valley-train terraces have generally been unsuccessful. The focus of this project has been to determine why these terrace deposits do not produce quality gravel.

EFFECTS OF FREEZE-THAW TESTS ON GRAVEL SAMPLES

The freeze-thaw testing procedures utilize a supersaturated solution of sodium sulfate to simulate the growth of ice crystals in the rocks during a natural freeze cycle. Figure 8 is a photograph of sodium sulfate crystals growing on the surface of a pebble. The growth of these crystals within the rock exerts pressure against the binding strength of the rock, and, if the inherent strength of the rock is less than the crystal-growth pressure, the rock breaks apart. The total amount of breakdown within a sample thus determines the quality of the deposits sampled in relationship to requirements set up by the experience of usage.

Breakdown of rock fragments during sodium sulfate testing occurs in three ways: (1) splitting along bedding planes and laminations of the rock fragment (Figures 9, 12a, 12c, and 13); (2) splitting along fractures in the

Figure 8. Sodium sulfate crystals growing on the surface of a pebble.

Figure 9. Splitting along laminations in pebbles during the sodium sulfate test.

rock at angles to the bedding planes (Figure 10); and (3) disaggregation of the individual grains that make up the rock (Figure 12a and 12c). It is also possible to have any combination of these cooperating to destroy a rock fragment (Figure 11). The depth and amount of liquid penetration in the individual fragments are dependent on porosity and permeability, which are controlled by the original cementation holding the grain together and by any alteration of this cementation through time.

Major changes that occurred in the rock fragments in the creation of a gravel deposit in the upper Allegheny River system were crushing, fracturing, and abrasion while the fragments were being transported in the glacier and by the meltwater streams flowing away from the glacier. Meltwater transportation breaks the rock into smaller, more stable sizes along zones of natural weakness within the original rock. The running-water transportation phase will tend to round off the sharp corners, and in general the greater the distance of transport the more rounded the fragment will become. The cementation of the fragment, however, will not be affected during transportation.

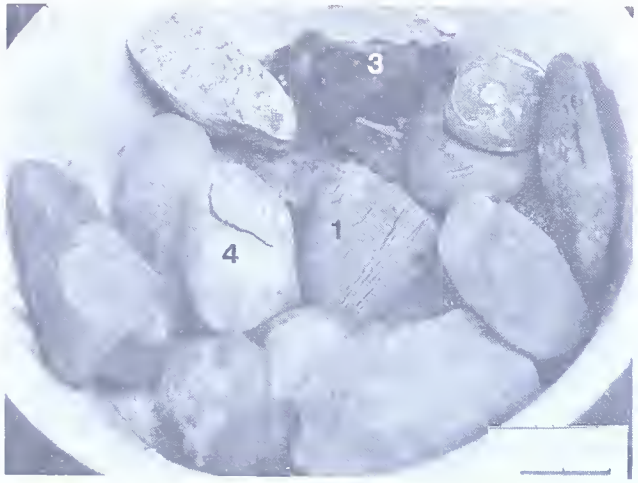
Changes in the cementation of the rock fragments occur after the rock fragments have been permanently deposited in the new site. Cementation

Figure 10. Splitting of pebbles in directions other than natural bedding planes during the sodium sulfate test.

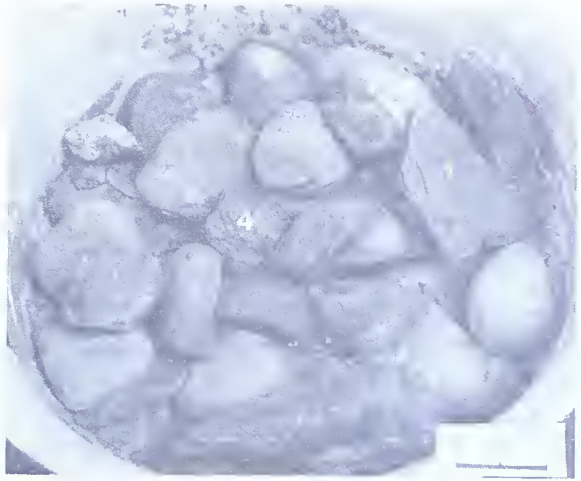
Figure 11. Splitting of pebbles along bedding planes and in directions other than bedding planes during the sodium sulfate test.

changes are of two types: (1) addition of new cement to the fragments and the consequent binding together of the fragments within the deposit to form a new solid rock mass; and (2) removal of cementation from the fragments susceptible to weathering.

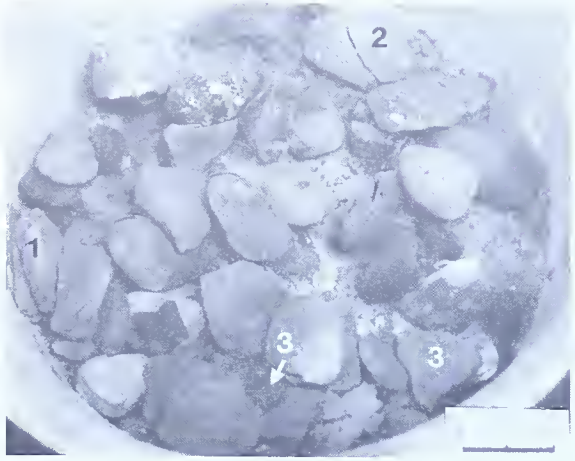
Many different chemical compounds are able to cement small mineral particles or rock fragments together to form a solid rock. The most common agents are silica, iron oxide, and calcium carbonate. Of these three, calcium carbonate is the most susceptible to alteration in nature. This sub-



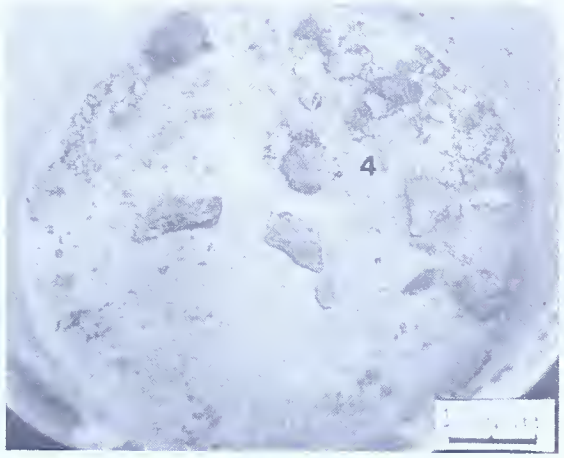
a. Size larger than 1 inch



b. Size larger than 3/4 inch and less than 1 inch

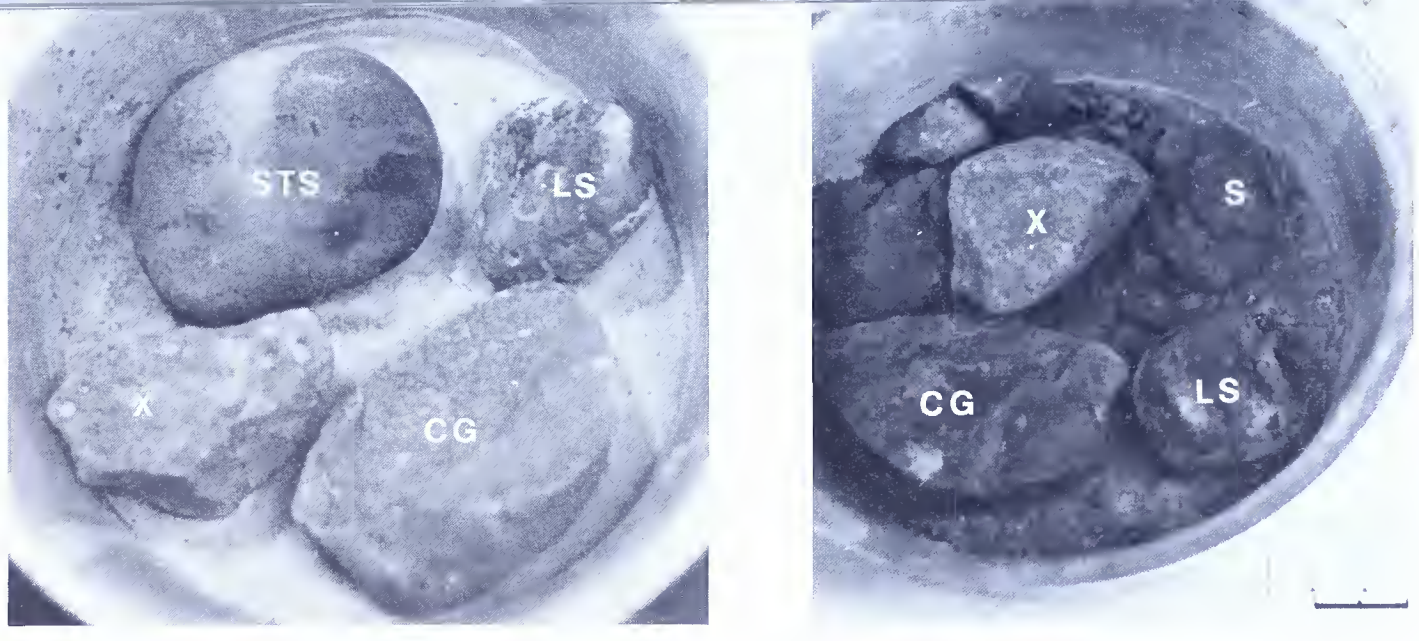


c. Size larger than 1/2 inch and less than 3/4 inch



d. Size larger than 3/8 inch and less than 1/2 inch

Figure 12. Gravel sample from the Brokenstraw Creek deposit, after five cycles of sodium sulfate testing. The sample was collected from a crush pile at the pit. 1, splitting along lamination planes; 2, splitting across lamination planes; 3, disaggregation; 4, flaking of thin plates from pebble.



Pre test Post test

Figure 13. Pre- and post-test comparison of four rock types.

Sample 1774—Four rocks from the Warren Sand and Gravel Company operation at Warren, Pennsylvania, all from barges too large for splitter, placed in $NaSO_4$ as is.

Conglomerate (CG):	Pre test	—96.07 g, mostly small quartz pebbles in a fine sand matrix, noncalcareous.
	Post test	—94.43 g, no breaking or fracturing, held up well.
Crystalline (X):	Pre test	—69.49 g, weathered, mostly quartz, rounded, red-orange stain in places, blocky shape, possible chunks and vein quartz, some dark minerals and some open pores on surface.
	Post test	—69.36 g, no fracturing at all, unaffected.
Limestone (LS):	Pre test	—166.27 g, silty, appears fresh on weathered face, fossiliferous.
	Post test	—165.84 g, some very minor fracturing or fine cracks developing, held up well but appears that flaking would occur if many more cycles were added.
Siltstone (STS):	Pre test	—128.27 g, light-medium-brown with some orange staining, noncalcareous, liquid soaks in rapidly.
	Post test	—largest piece 33.91 g, shattered into pieces. It appears that this rock crumbled along outside and along fractures (probably bedding planes) into pieces; some flaking along the fractures.

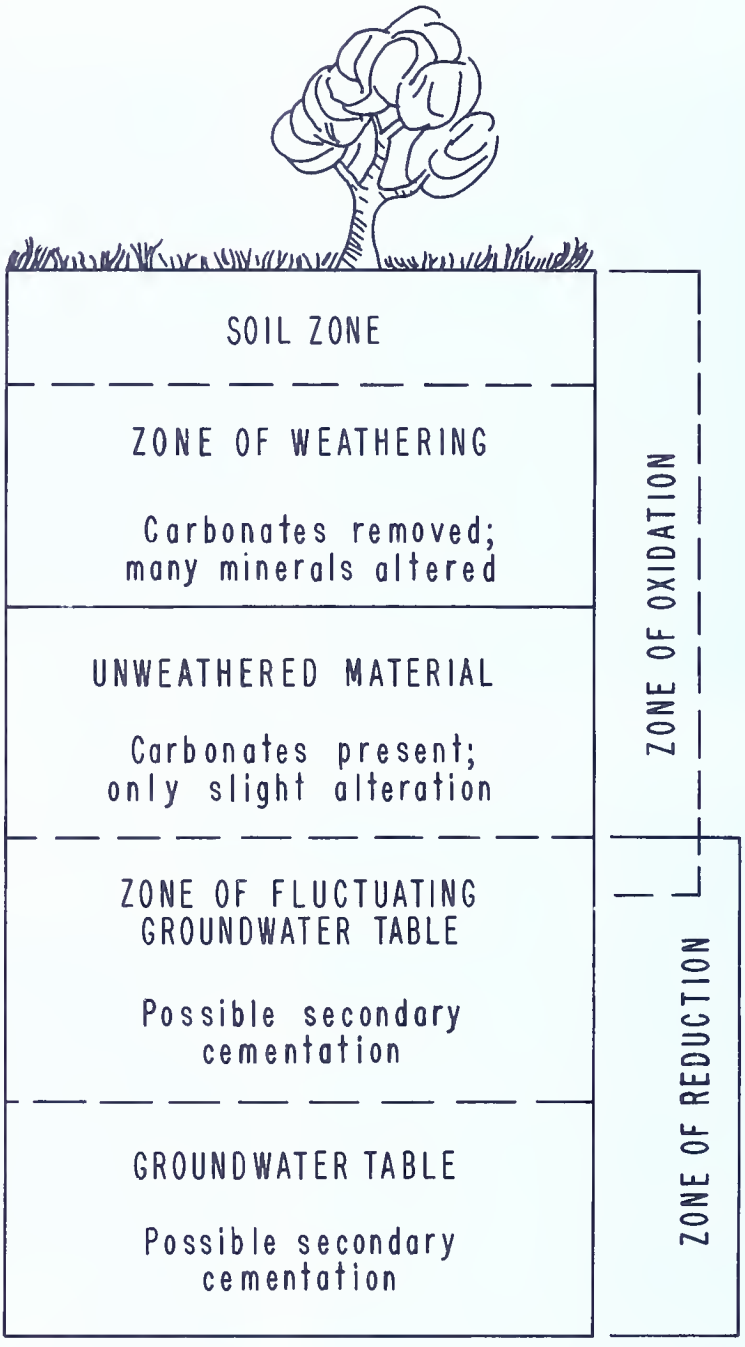


Figure 14. Profile of a gravel deposit showing different effects of weathering with depth.

stance is very soluble in slightly acidic water such as develops where water passes through decaying organic material. A sequence of events occurring within the gravel deposits may be as follows (Figure 14):

1. Rainwater falls on the surface, soaking into the ground.

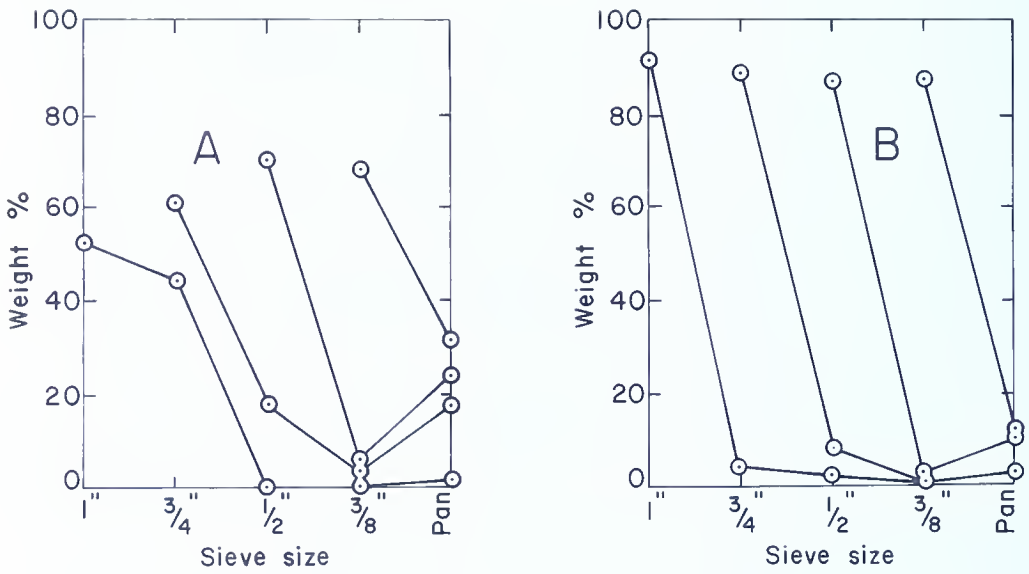
2. This water becomes slightly acidic as it slowly passes through the organic layer of the soil.
3. This water reacts with the calcium carbonate contained in the rock making up the deposit, removes the calcium carbonate from the rock, and carries it away in solution. Calcium carbonate (calcite) occurs in nature to form limestone (rock composed almost entirely of calcite) and also as a cement holding individual grains together. As the acid waters react with the calcium carbonate in the rock, they will be neutralized and the now carbonate-rich water will continue moving downward to the groundwater table. The depth of penetration of this weathering process is determined by the porosity and permeability of the deposit and by time. Older deposits will be weathered deeper than younger deposits having the same porosity and permeability. If there is some kind of an impermeable seal, such as a clay layer or till blanket over the top of the deposit keeping the water from entering the deposit, very little weathering will take place (Figure 15). Sample A (Figure 15) was collected in the lowest part of a pit in an area in which there was no impermeable cover of any kind. The deposit here was gravel up to the surface. Samples B were collected from an area of recent expansion of the pit, where an 8-foot cover of till and clay had to be stripped away to uncover the gravel. Note the lack of limestone in sample A and the change in the siltstones during the freeze-thaw test in comparison to the changes in samples B. Figure 16 demonstrates the types of compositional changes caused by weathering that take place vertically in a gravel deposit where there is no interruption in the downward movement of the water.

Sample A (Figure 16) was collected from a crush pile at the outlet end of a crusher and is representative of the composition of the gravel from just below the weathered/unweathered-zone contact to the surface. Sample B was collected as far below the weathered-zone contact as possible.

The weathered-zone sample is higher in brown siltstones, low in gray siltstones, and contains no sandstones, whereas the unweathered-zone sample is high in gray siltstones, has a large increase in crystallines, and contains a substantial amount of sandstones.

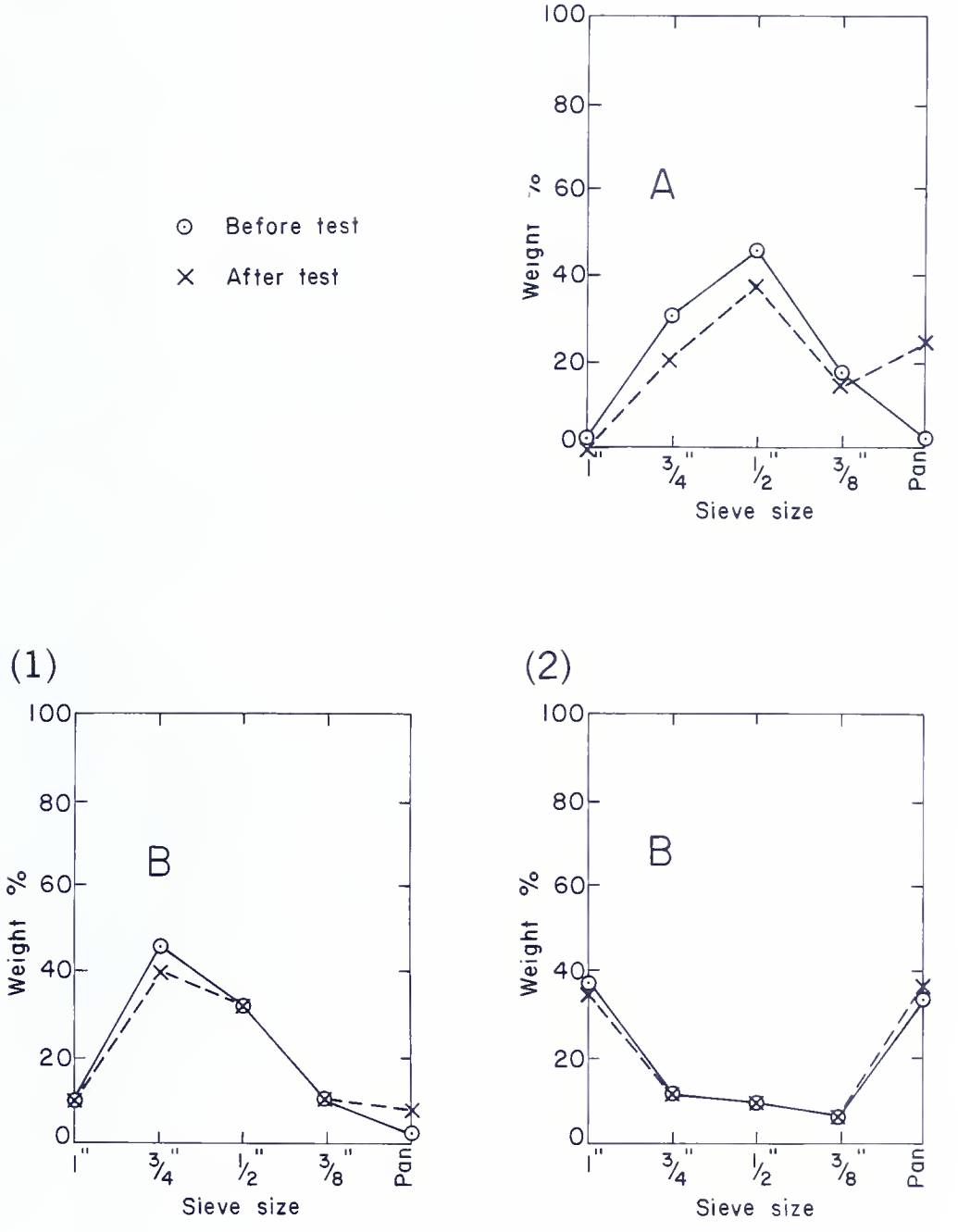
Weathering processes have altered most of the gray siltstones present in the upper part of the deposit to a brown color. The crystalline and sandstone components have been extensively altered within the zone of weathering, enabling them to be broken up during the crushing operation. The other notable change between the two samples is the amount of breakdown during the freeze-thaw test of the siltstones. This increased breakdown is due to the weakening of the cementing bond of the individual grains of the rock.

Tionesta Sand and Gravel Co., Cooperstown operation, Venango County						
	A		B			
	Below water level in dragline pool Freeze-thaw test by weight percent		From under clay blanket (1) Freeze-thaw test by weight percent		From under clay blanket (2) Freeze-thaw test by weight percent	
	Pre	Post	Pre	Post	Pre	Post
Gray siltstone	47.4	32.0	46.4	44.0	36.4	32.4
Gray calcareous siltstone	- -	- -	- -	- -	- -	- -
Brown siltstone	15.9	7.0	3.2	2.9	37.7	36.0
Brown calcareous siltstone	- -	- -	- -	- -	- -	- -
Crystalline	8.1	6.3	11.6	11.0	4.7	3.8
Chert	1.2	1.1	3.3	3.0	10.8	7.6
Limestone	- -	- -	4.4	1.1	6.2	7.7
Sandstone	27.4	20.6	31.2	28.7	4.2	3.5
		33% loss		9.3% loss		9% loss



Sieve analysis of each sieve after the freeze-thaw test. The original weight percent of each sieve before the test is 100 percent.

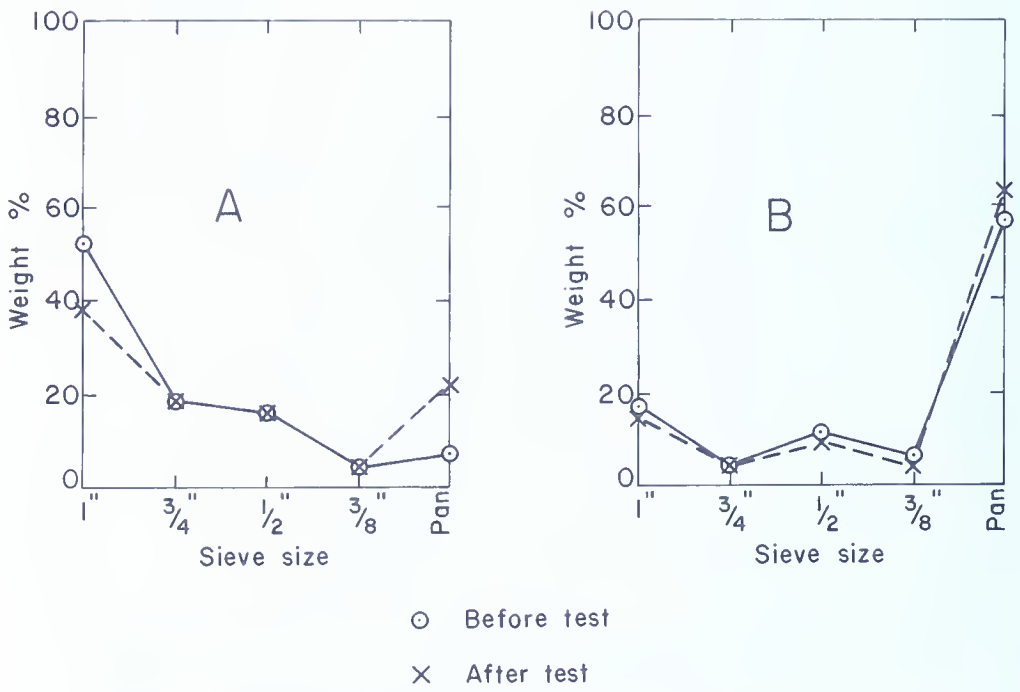
Figure 15. Pebble size distribution and lithologic composition changes in a gravel deposit where (A) the weathering zone is not protected from water penetration, and (B) the weathering zone is protected from water penetration. Note the presence of limestone in (B) and only a 9 percent loss in the freeze-thaw test. Samples are from Tionesta Sand and Gravel Company, Cooperstown operation, Venango County.



Sieve analysis of the total sample before and after the freeze-thaw test.

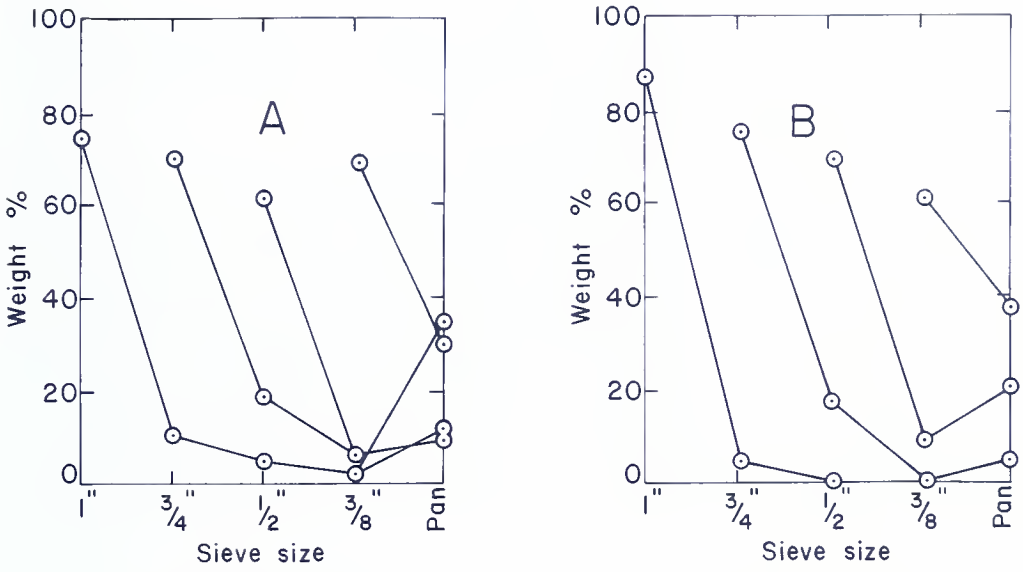
Figure 15. (Continued).

Emlenton Limestone and Gravel Co., Pittsfield operation, Warren County				
	A Working face Material crushed and screened; includes weathered material		B Working face Not crushed. Samples collected from below weathered zone	
	Pre	Post	Pre	Post
Gray siltstone	15.7	5.0	52.1	35.5
Gray calcareous siltstone	3.3	2.7	- -	- -
Brown siltstone	77.5	54.1	14.2	12.5
Brown calcareous siltstone	- -	- -	- -	- -
Crystalline	2.0	2.0	14.2	14.2
Chert	1.5	1.3	1.0	1.0
Limestone	- -	- -	2.3	1.4
Sandstone	- -	- -	12.1	9.6
		34.9% loss		25.4% loss



Sieve analysis of total sample before and after the freeze-thaw test.

Figure 16. Pebble size distribution and lithologic composition changes in a gravel deposit, (A) within the zone of weathering, and (B) below the zone of penetration. Note the presence of limestone in (B) and the smaller loss in the freeze-thaw test. Samples are from the Emlenton Limestone and Gravel Company, Pittsfield operation, Warren County.



Sieve analysis of each sieve after the freeze-thaw test. The original weight percent of each sieve before the test is 100 percent.

Figure 16. (Continued).

4. Once the downward-percolating water reaches the water table, conditions change. The waters will be nearly saturated with calcium in solution. Any changes in the carbon dioxide concentration and/or temperature of the water will cause precipitation of the calcium in the form of calcium carbonate, causing the cementation of grains. This cementation process can start at any depth below the zone of weathering. It is believed to be mainly concentrated, however, within the zone of groundwater fluctuation (Figure 14) at the interface between the zone of oxidation and the permanent groundwater table.

   This cementation can cause problems in the development of the gravel operation. The zone of cementation usually occurs either within a lens of the deposit, in which a layer of material of relatively homogeneous size will be cemented, or as an irregular surface forming pinnacles that extend up into the uncemented parts of the deposit. If the cementation is intense, it can cause difficulty in excavating the gravel. The cement can usually be broken by the front loader during digging. In this case, the operator will normally place the larger cemented boulders to one side. However, if the cementation becomes too heavy, the operator has to work around the cemented zone, leaving the cemented material in place in the pit. The real problem with

this cemented material is that it breaks down into the individual grains during freeze-thaw testing, causing the deposit to be designated as unsuitable as a Class A aggregate, even though the main constituents of the gravel are sound.

Field testing for presence of calcium carbonate in the gravel and determination of the depth of weathering is very simple. Calcium carbonate reacts by forming bubbles on the rock surface when a weak solution of hydrochloric acid (commercially called muriatic acid) is applied. The test solution is made by mixing one part acid to ten parts water. It is best carried in a plastic dropper bottle. A drop of the solution is placed on a fresh surface of the rock fragment, and, if calcium carbonate is present, bubbles will develop. The depth of weathering can be quickly determined using this solution. It is usually necessary to break the rock to expose fresh surfaces to get a good test. This is especially true in the fine siltstones that have only a minor amount of calcium carbonate cement.

ANALYSIS OF FREEZE-THAW TESTS ON GRAVEL SAMPLES

The key to producing quality gravel from the deposits in northwestern Pennsylvania is in understanding what happens to the individual particles that make up the deposit. This, combined with an understanding of the depositional and postdepositional history of the deposit, will enable an operator to evaluate the potential maximum utilization of the deposit. Understanding the characteristics of the deposit will also determine the operational procedures and aid in establishing the design of the crushing plant to obtain the highest quality of material possible from a particular deposit.

The following discussion is based on the results of freeze-thaw testing on a number of samples collected from deposits throughout the northwest region. The interpretations are aimed at demonstrating how one can study samples and determine what changes are taking place during the test, and from this improve the processing procedures to obtain a higher quality product.

The lithologic studies of the gravel deposits show five categories of rock fragments making up the deposits. The effects of freeze-thaw testing on each rock type is shown on Table 10. This table is divided into the weathered and unweathered characteristics of the individual rock types and shows how each reacts to the freeze-thaw test. Color of the rock fragment gives an indication of the weathering that has taken place. The yellow and brownish colors are the results of breakdown of iron-bearing minerals, which leave a residue of iron oxide coating the grains. The best indication of

Table 10. *Effects of the Sodium Sulfate Tests on Different Rock Types*

ROCK TYPE	COLOR	UNWEATHERED	COLOR	WEATHERED
Siltstone	Greens and dark gray	Generally stable; splits into stable pieces along bedding lamination. Some loss due to flaking along very thin laminations; splitting along fractures indueed by the crusher.	Shades of brown	Splits along bedding lamination; great deal of flaking and disaggregation of individual grains; often total disintegration of rock. Often removed by impactor during crushing.
Crystalline	Variable, no iron stain	No effect on coarse crystalline type; major breakdown of metamorphic rocks having micaceous lamination zones.	Brown stained	Breakdown depends on degree of weathering. Coarse crystalline fragments will disaggregate to individual crystals; these weathered fragments are usually broken up during crushing.
Chert	Dark gray to light gray	No breakdown	Light brown	Some minor splitting where calcareous material has been removed by weathering.
Limestone	Gray	Generally very stable; will split into stable pieces along bedding lamination.		Generally not present in weathered material. The calcareous rock is the first to go in the weathered zone. When present, the rock will usually disintegrate during the test.
Sandstone	White, gray, green	Will split along laminated zones. Disaggregation occurs when porosity is high and cementing of grains is weak. Splitting along crushing-induced fractures is common.	Yellow to brown	Total disaggregation occurs when cementing media has been removed or weakened by weathering. Often removed from samples by the impactor during crushing.

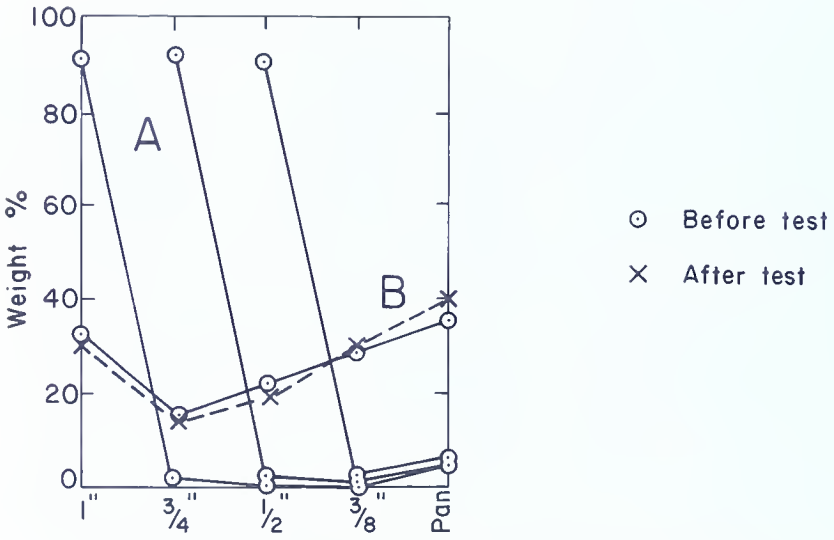
unweathered material is the presence of calcium carbonate in the sample. Understanding how and why the different types of rock break down enables one to analyze the production methodology and sometimes upgrade the end product.

The following figures detail the compositional changes that take place during the freeze-thaw test in samples collected from a wide range of de-

a

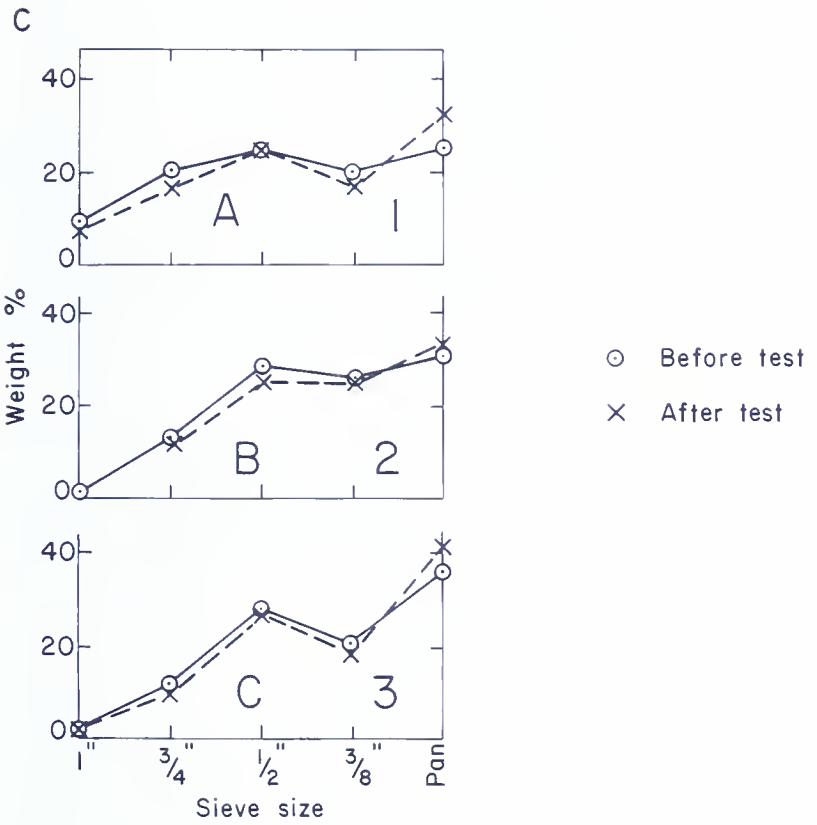
	A		B		
	Pre	Post	Dredge 1.	Crush pile 2.	Crush pile 3.
Gray siltstone	10.9	8.6	49.9	50.2	46.3
Gray calcareous siltstone	2.7	2.1	5.4	28.3	18.6
Brown siltstone	77.8	66.5	17.1	4.3	8.9
Brown calcareous siltstone	- -	- -	5.6	2.3	5.3
Crystalline	5.5	5.0	14.9	9.6	9.3
Chert	2.1	1.1	5.0	3.8	7.3
Limestone	- -	- -	3.1	- -	- -
Sandstone	1.0	- -	- -	1.5	2.7

b



Column A shows the lithologic composition before (pre) and after (post) the freeze-thaw test. Columns under B give pre-test composition only. The total loss of countable pebbles that disappeared from individual sieves during the freeze-thaw test (column A) was 15.9 percent. The numbers represent weight percents.

Figure 17. Lithologic composition and grain size distribution of gravel samples collected from the Warren Sand and Gravel Company operation at Warren, Pennsylvania.



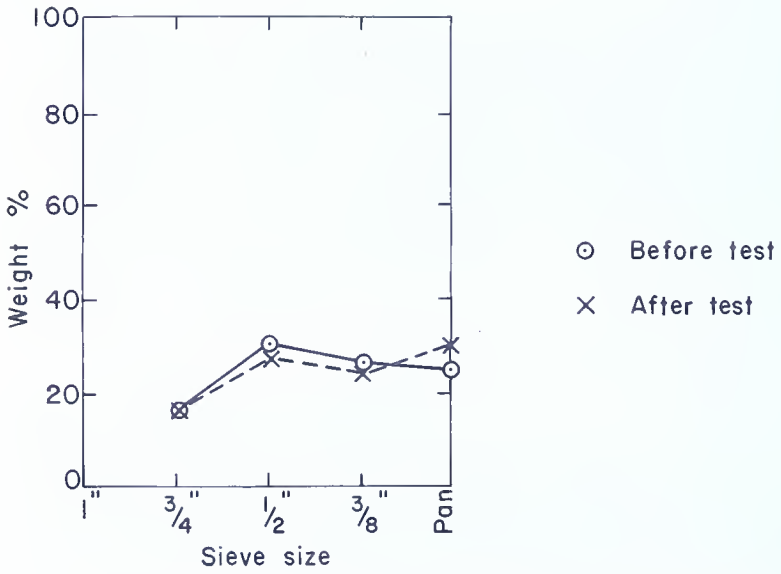
A shows the changes in grain size distribution of the gravel sample in each sieve size after the freeze-thaw test. B shows the overall size distribution before and after the test. The sample was collected from the unloading point of the dredge. Grain size distribution of the gravel samples in column B of the table before and after the freeze-thaw test. 1, collected from the dredge; 2 and 3, collected from a separate crush pile after processing.

Figure 17. (Continued).

posits throughout the study area. Figures 17 through 19 are the analytical results obtained from an operation producing approved Class A aggregate. Figure 17b shows what happens to the samples within the individual sieve size categories and also shows the overall changes that have taken place after all sizes have been mixed together and resieved. Overall, very little change has taken place. There is a slight reduction of size, i.e., of 1-inch material caught on the 3/4-inch sieve and passing through of smaller material to the pan. Overall, there has been a loss of 15.9 percent of identifiable material from the sample. One should keep in mind that only the pebbles retained on the original sieve size were counted. Therefore, loss repre-

sents the breakdown of the material to a smaller sieve size. Evaluation of the changes by lithologic composition shows the greatest change is in the brown siltstone (11.3 percent). The plot of changes in individual grade sizes shows most of this material to have passed through the sieve stack to the pan. A small percentage, however, has passed through to the next smaller sieve, i.e., 1 inch to 3/4 inch, 3/4 inch to 1/2 inch, etc.; the rest goes directly to the pan. This is believed to indicate a flaking and disintegration of the edges of the fragments, probably along fractures induced by the primary crushing of the material. This sample (Figure 17, sample A) was collected at

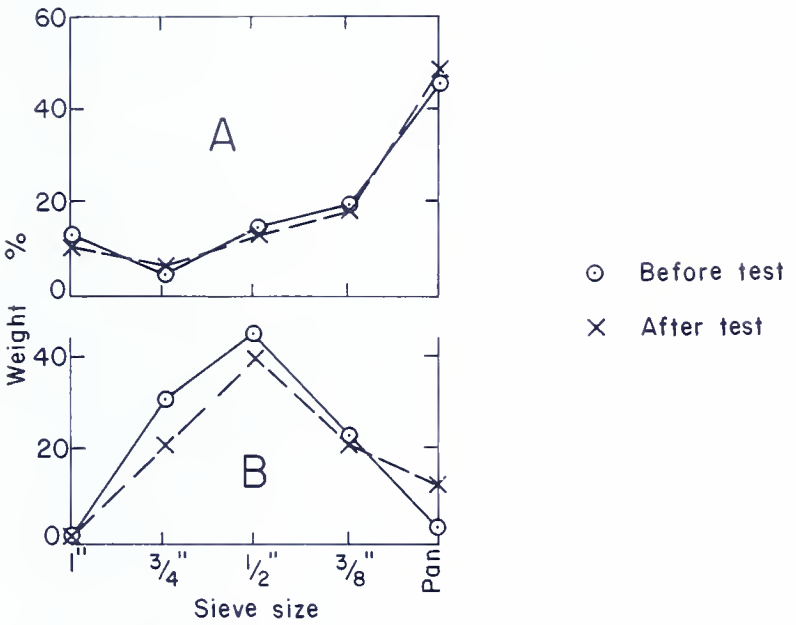
	Franklin Dredge 2B pile by weight percent
Gray siltstone	25.8
Gray calcareous siltstone	10.7
Brown siltstone	26.9
Brown calcareous siltstone	0.2
Crystalline	12.0
Chert	5.7
Limestone	7.4
Sandstone	11.5



Sieve analysis of total sample before and after the freeze-thaw test.

Figure 18. Pebble size distribution and lithologic composition of a gravel sample collected from a crush storage pile at the Franklin dredge operation, Venango County.

	A Working face Freeze-thaw test by weight percent		B Conneaut Lake S&G Crush pile Freeze-thaw test by weight percent	
	Pre	Post	Pre	Post
Gray siltstone	30.0	30.0	51.9	45.8
Gray calcareous siltstone	8.3	7.3	- -	- -
Brown siltstone	26.0	24.5	- -	- -
Brown calcareous siltstone	6.3	7.2	3.8	4.2
Crystalline	18.1	18.1	12.2	13.1
Chert	1.0	1.0	4.0	2.1
Limestone	10.0	10.0	28.0	25.5
Sandstone	- -	- -	- -	- -
		1.9% loss		9.3% loss



Sieve analysis of the total sample before and after the freeze-thaw test.

Figure 19. Pebble size distribution and lithologic composition of gravel samples collected from (A) the working face, and (B) the crush pile at the Conneaut Lake Sand and Gravel Company operation near Conneaut Lake, Crawford County.

the barge unloading point. The material had at this point gone through a first-stage crushing on the dredge to reduce the larger cobbles to a workable size. Further processing, especially the use of a high-speed impactor, would eliminate weaker material from the sample. Figure 17c shows the overall

changes in other samples collected from this operation. There is not much difference in these samples, but the greatest amount of change does occur in the sample collected at the barge unloading dock (A).

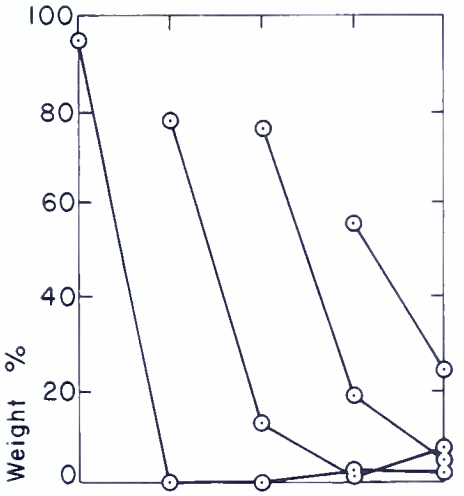
Figure 18 shows the lithologic composition and grain size distribution of a sample collected from the Franklin dredge operation. The main compositional difference from the Warren samples is the increase in limestone and sandstone. Freeze-thaw breakdown is minimal. A comparison of the pebble-size distribution changes during freeze-thaw testing with the Warren samples undergoing the same type of testing shows mainly a difference in splitting and flaking that is related to crushing-induced fractures. The main difference between the two deposits is in the crushing treatment. The Atlas Sand and Gravel operation (Figure 20) did not have its impactor in operation; therefore, the weaker siltstones were not being broken down during crushing. The importance of crushing technology to producing quality aggregate cannot be overemphasized. The crushing and screening operation produces the size of particles and crush count needed for a particular use. The crushing and use of the impactor also eliminate the rock fragments that break down in the freeze-thaw test.

However, crushing is not everything. In order to produce quality gravel the operator has to understand the complexities of the deposit, and, whenever possible, separate the less desirable material before it goes into the crusher.

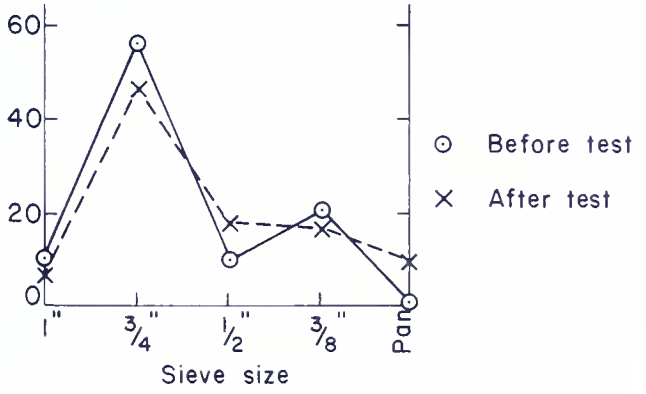
The importance of the recognition of weathered material is clearly shown in the following samples. The Vincent Sand and Gravel operation (Figure 21) is located in a dissected valley-fill deposit 1 mile north of Fosters Corners (Franklin quadrangle), Venango County. The deposit is an ice-contact kame as far as the northwest quarter of the crossroads and is stratified outwash in the southeast quarter. The deposit is intensely weathered to the bottom of the working face. Figure 21 shows the lithologic composition of the deposit along with the size distribution information. Freeze-thaw losses are large—52 percent in the outwash deposit and 32 percent in the kame. Breakdown appears to be disaggregation to individual grains, as shown by the increase in pan-size particles from each sieve. This deposit is over 60 feet thick. The weathering of rock particles has occurred throughout this total thickness. It probably would not be possible to improve this deposit to meet quality standards.

However, where the weathered zone is much thinner and unweathered gravel can be exposed, it is possible to improve the quality of the crushed product by selective crushing. For example, Figure 22 shows the pebble size distribution and lithologic composition of two crushed gravel samples collected from the same pit. Sample A was collected from a crusher that was working in unweathered material, and sample B was collected from a crusher that was working with material from the entire face of the pit,

	Freeze-thaw test by weight percent	
	Pre	Post
Gray siltstone	28.7	25.1
Gray calcareous siltstone	17.9	15.9
Brown siltstone	9.3	7.1
Brown calcareous siltstone	22.7	16.7
Crystalline	13.5	13.5
Chert	5.6	5.6
Limestone	2.2	2.6
Sandstone	– –	– –
		14.5% loss



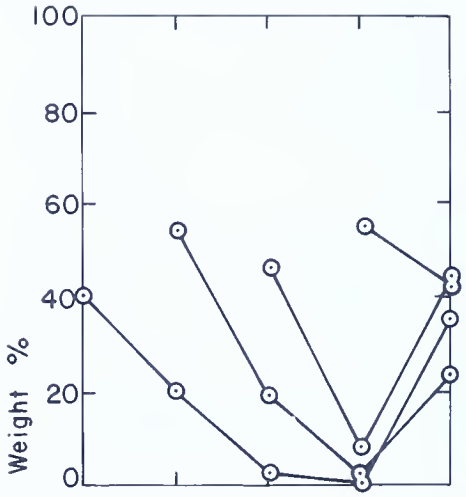
Sieve analysis of each sieve after the freeze-thaw test.



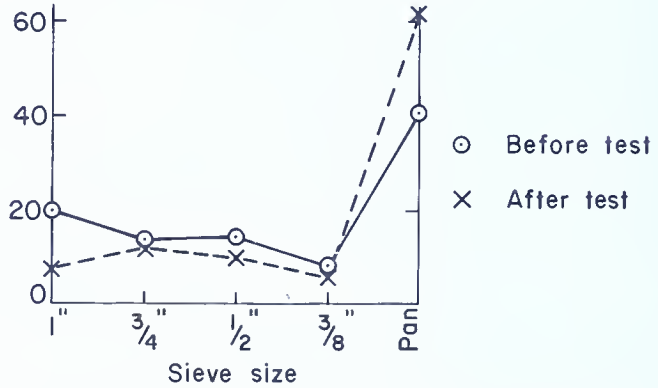
Sieve analysis of the total sample before and after the freeze-thaw test.

Figure 20. Pebble size distribution and lithologic composition of a gravel sample collected from a crush pile at the Atlas Sand and Gravel Company operation south of Conneaut Lake, Crawford County. The material has not gone through the impactor.

	Upper part of pit, southwest quarter	
	Freeze-thaw test by weight percent	
	Pre	Post
Gray siltstone	17.1	8.7
Gray calcareous siltstone	- -	- -
Brown siltstone	- -	- -
Brown calcareous siltstone	- -	- -
Crystalline	8.0	4.4
Chert	1.9	1.7
Limestone	- -	- -
Sandstone	73.0	33.2
		52.0% loss



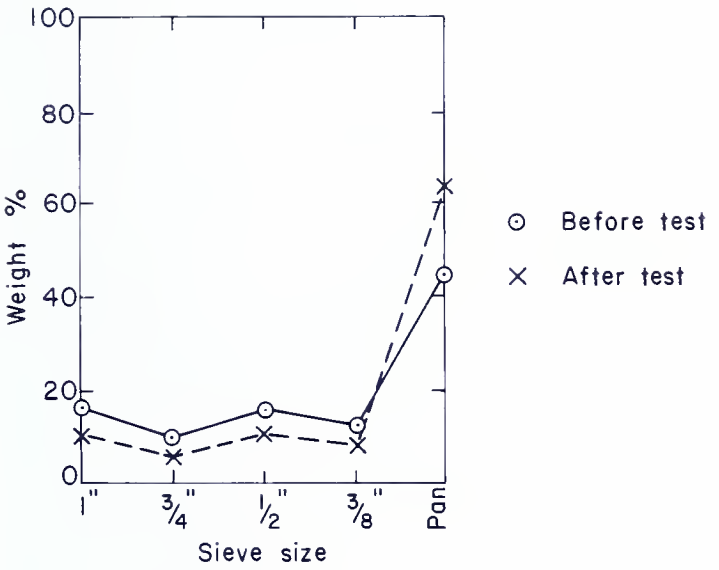
Sieve analysis of each sieve after the freeze-thaw test.



Sieve analysis of the total sample before and after the freeze-thaw test.

Figure 21. Pebble size distribution and lithologic composition of gravel samples collected at the crossroads 1 mile (1.6 km) north of Fosters Corners, from the Vincent Sand and Gravel operation, Venango County.

	Northeast quarter	
	Freeze-thaw test by weight percent	
	Pre	Post
Gray siltstone	2.5	2.5
Gray calcareous siltstone	- -	- -
Brown siltstone	92.0	61.2
Brown calcareous siltstone	- -	- -
Crystalline	0.7	0.7
Chert	4.8	3.7
Limestone	- -	- -
Sandstone	- -	- -
		31.9% loss



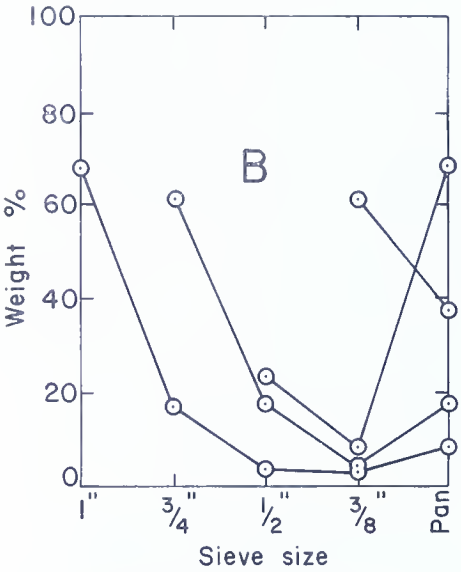
Sieve analysis of the total sample before and after the freeze-thaw test.

Figure 21. (Continued).

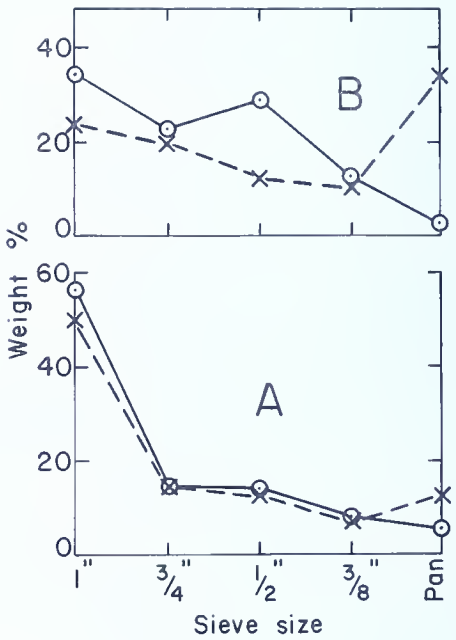
which included 15 feet of weathered gravel. The freeze-thaw test created very little breakdown in the sample collected from below the weathered zone. However, the sample containing weathered material shows considerable breakdown. The greatest amount of breakdown occurs in the half-inch size fraction. This is probably due to the crushing of large weathered pebbles that break to form 1/2- to 3/4-inch fragments. When these weathered crushed fragments are subjected to the freeze-thaw test, they disaggregate to pan-size particles.

Figure 23 is another example of the difference in response to the freeze-thaw test in samples that (A) contain weathered rocks, and (B) are from below the weathered zone.

	A Unscreened	B Sieved, crushed, and washed
	by weight percent	
Gray siltstone	51.3	60.0
Gray calcareous siltstone	13.4	16.8
Brown siltstone	17.3	9.4
Brown calcareous siltstone	5.2	1.1
Crystalline	0.6	4.4
Chert	0.4	0.8
Limestone	11.7	4.2
Sandstone	0.4	2.9



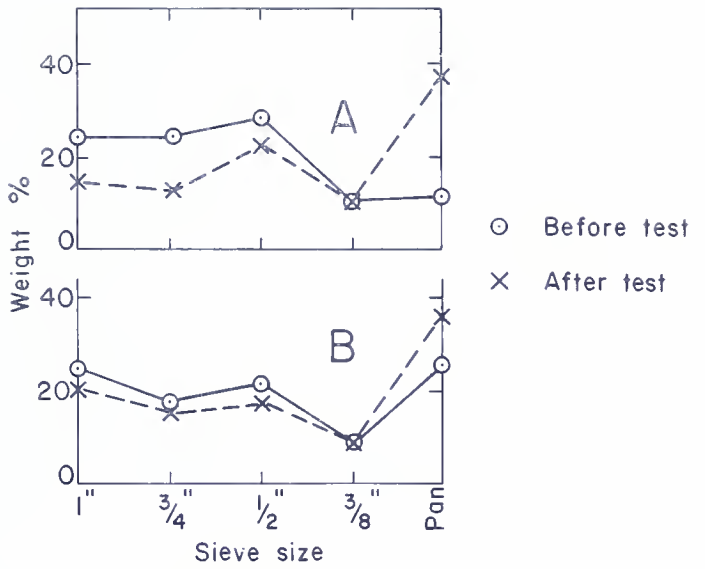
Sieve analysis of each sieve after the freeze-thaw test.



Sieve analysis of the total sample before and after the freeze-thaw test.

Figure 22. Pebble size distribution and lithologic composition of gravel samples collected at the Brokenstraw Sand and Gravel Company, near Pittsfield, Warren County. Sample A was collected from below the weathered zone; sample B includes weathered-zone material.

	A Crush pile contains weathered material		B Dragline below weathered zone	
	Freeze-thaw test by weight percent		Freeze-thaw test by weight percent	
	Pre	Post	Pre	Post
Gray siltstone	38.9	27.9	37.5	35.9
Gray calcareous siltstone	13.9	13.4	17.8	17.4
Brown siltstone	38.6	27.9	27.5	22.0
Brown calcareous siltstone	– –	– –	5.6	5.4
Crystalline	4.9	4.3	2.7	2.7
Chert	1.2	1.2	0.7	0.7
Limestone	– –	– –	6.6	6.5
Sandstone	2.5	0.8	1.6	1.1
		24.4% loss		8.4% loss



Sieve analysis of the total sample before and after the freeze-thaw test.

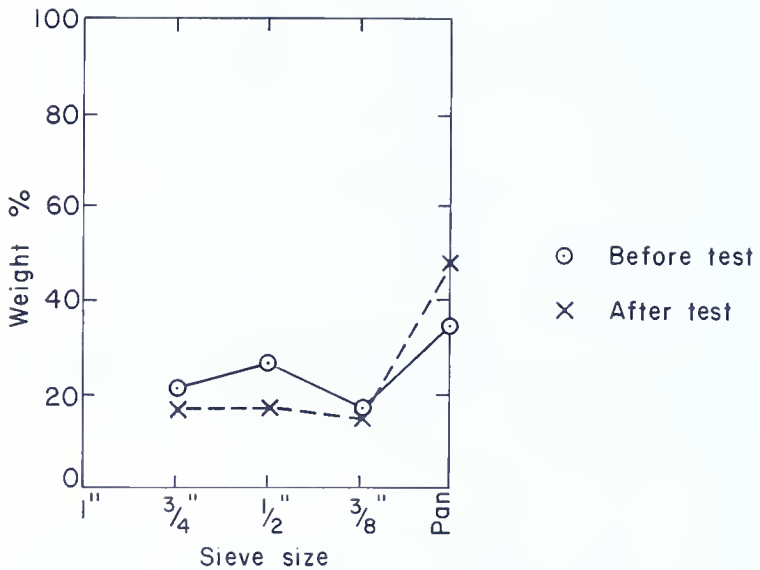
Figure 23. Pebble size distribution and lithologic composition of a gravel sample collected at the Hasbrouck Sand and Gravel Company pit at Hydetown, Crawford County.

In this sample 22 percent of the freeze-thaw breakdown occurs in the gray and brown siltstone in the weathered zone and only 2 percent occurs in the same lithologies in the unweathered sample. Overall, there is a 16 percent improvement in the quality of the gravel due to the elimination of the weathered gravel before crushing.

It is quite apparent from the information obtained from the two deposits mentioned above that removal of the upper weathered-zone material improves the quality of crushed aggregate. The method of crushing is also important. However, sometimes that is not enough to produce an aggregate that meets the quality standards established by the Pennsylvania Department of Transportation (PennDOT).

One gravel-pit operator north of Titusville, Pennsylvania, was having difficulty in maintaining quality to meet highway construction requirements. He was stripping away the weathered gravel and had a new crushing plant. However, sometimes the aggregate would pass the freeze-thaw test, and sometimes it would not. Evaluation of the freeze-thaw test shows that the major breakdown of material occurs in the siltstones (Figure 24). Examina-

	Freeze-thaw test by weight percent	
	Pre	Post
Gray siltstone	40.8	34.2
Gray calcareous siltstone	30.3	23.2
Brown siltstone	- -	- -
Brown calcareous siltstone	- -	- -
Crystalline	7.6	7.7
Chert	0.3	- -
Limestone	19.7	13.9
Sandstone	1.4	1.0
		19.9% loss



Sieve analysis of the total sample before and after the freeze-thaw test.

Figure 24. Pebble size distribution and lithologic composition of a gravel sample collected near Lake Pleasant, Erie County.

tion of the sieve analysis shows that the largest breakdown during the freeze-thaw test occurs in the 1/2-inch size fraction. The lithologic studies established that this sieve fraction is made up mostly of angular fragments of siltstone. A study of the working face indicated that the source of these siltstone fragments was the crushing of large, flat siltstone slabs ranging in size from 2 inches thick and 8 inches long and wide to 6 inches thick and 2 feet long. These slabs are from the local "bedrock" and have undergone very little transportation before being deposited in their present location. Observation indicated that the removal of these slabs before crushing would improve the deposit. Therefore, a special jig was constructed that removed the larger slabs as a first screen before primary crushing. When this slabby material was removed, the quality of the crushed product improved and was consistent.

CONCLUSIONS

Studies of the lithologic composition of the various gravel deposits and their resistance to freeze-thaw breakdown has established definite characteristics to look for in evaluating the potential for developing a gravel pit. Table 10 evaluates the characteristics of the major components of the deposits and their resistance to the freeze-thaw test.

Detailed laboratory examination of the freeze-thaw resistance of natural gravel deposits in northwestern Pennsylvania has shown that it is possible to improve the quality of some gravel deposits to meet requirements of the Pennsylvania Department of Transportation for use as Class A construction aggregate. This improvement is determined by understanding the characteristics of the deposit, working the pit to bring the best possible material to the crush plant, and designing a crushing procedure to eliminate the detrimental material in the deposit.

Outwash valley-train deposits have the greatest potential for development, as they cover a sufficient area for development of the resource. Ice-contact kame deposits are excellent sources of crushed gravel where the deposit is made up of large, cobble-size material. This type of deposit requires special pit operations because of extreme and frequent changes in particle size throughout the deposit. Ice-contact alluvial fans and deltas are excellent deposits, usually containing coarse material for operators who do not require large quantities, as these deposits are usually limited in size. The controlling factor is that the deposit must be thick enough to have adequate unweathered gravel to produce the volume required to make the operation economically viable. It is very important to determine the depth and extent of weathering that has taken place in the deposit as part of the deposit evaluation. Experience has shown that this weathered-zone material must be removed prior to crushing if there is to be any chance of producing a quality crushed aggregate.

The following is a brief outline of the significant factors to be considered in attempting to establish an aggregate-producing operation.

A. Verify a demand for quality aggregate.
B. Determine the location of the market. Distance of the source from the market will be a major economic factor.
C. Prospect for favorable gravel resources:
    1. Explore favorable depositional types of deposits, e.g., valley-train deposits, kames, and alluvial fans.
    2. Determine areal extent and thickness of the deposit.
    3. Determine depth of weathering. This will establish the amount of stripping necessary to expose the unweathered material and will determine the amount of available unweathered material.
    4. Sample the unweathered material and determine the size and composition of the individual constituents (particles) of the deposit and the lateral variation of the deposit. This will establish the operational procedures of the pit and crush plant.

GLOSSARY

Ablation till. Loosely consolidated rock debris, formerly contained by a glacier, that accumulated in place as the surface ice was removed by melting.

Delta. The low, nearly flat, alluvial tract of land deposited at or near the mouth of a river, commonly forming a triangular or fan-shaped plain, resulting from the accumulation of sediment at the point where the river flows into a wider, still body of water.

Drift (as used by a glacial geologist). A general term applied to all rock material (clay, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.

Englacial till. Material that has been contained, embedded, or carried within the body of a glacier or ice sheet and that was deposited without further transportation.

End moraine. A moraine that is being produced at the front of an actively flowing glacier at any time; a moraine that has been deposited at the lower or outer end of a glacier.

Esker. A long, low, narrow, sinuous, steep-sided ridge or mound composed of irregular stratified sand and gravel that was deposited by a subglacial or englacial stream flowing between ice walls or in an ice tunnel of a retreating glacier, and was left behind when the ice melted.

Glaciofluvial. Pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by such streams.

Ground moraine. The rock debris dragged along in and beneath a glacier or ice sheet; also, this material after is has been deposited or released from the ice during ablation to form an extensive, fairly even, thin layer of till, having a gently rolling surface.

Ice-contact deposit. Stratified drift deposited in contact with melting glacier ice.

Interlobate moraine. A lateral moraine formed along the line of junction of, and roughly parallel to, the axes of two adjacent glacial lobes that have pushed their margins together.

Kame. A low, steep-sided hill, mound, knob, hummock, or irregular ridge, composed chiefly of poorly sorted and stratified sand and gravel deposited by a glacial stream against or upon the margin of a melting glacier.

Kame delta. A flat-topped, steep-sided hill of well-sorted sand and gravel deposited by a meltwater stream flowing into a proglacial lake; the upper margin of the delta was built in contact with glacier ice.

Kame moraine. (A) a terminal or end moraine that contains numerous kames; (B) a group of kames along the front of a stagnant glacier.

Kettle (as used by a glacial geologist). A steep-sided, usually basin- or bowl-shaped hole or depression in glacial-drift deposits (especially outwash and kame); it does not have surface drainage and often contains a lake or swamp; it is believed to have formed by the melting of a large, detached mass of stagnant ice that was wholly or partly buried in glacial drift.

Lodgment till. A basal till commonly characterized by compact fissile structure and containing stones oriented with their long axes generally parallel to the direction of ice movement.

Moraine (as used by a glacial geologist). A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacial ice in a variety of topographic landforms that are independent of control by the surface on which the drift lies.

Outwash (as used by a glacial geologist). Stratified, sorted detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the moraine or margin of a former glacier.

Outwash delta. A small plain of gravel and sand built at the mouth of a glacial meltwater stream flowing into a standing body of water.

Outwash plain. A broad, outspread, flat or gently sloping alluvial sheet of outwash deposited by meltwater streams flowing in front of or beyond the end moraine of a glacier, and formed by coalescing outwash fans.

Recessional moraine. An end moraine built during a temporary but significant halt or pause in the final retreat of a glacier. Also, a moraine built

during a slight or minor readvance of the ice front during a period of general recession.

Stratified drift. Glaciofluvial drift consisting of sorted and layered material deposited by meltwater streams or settled from suspension in a body of quiet water adjoining the glacier. A general term used when a more specific descriptive term is not possible or necessary.

Terminal moraine. An end moraine, extending across a glacial valley as an arcuate or crescent ridge, that marks the farthest advance or maximum extent of a glacier; the outermost end moraine of a glacier. It is formed at or near a more-or-less stationary edge, or at a place marking the cessation of an important glacial advance.

Valley train. A long, narrow body of outwash, deposited by meltwater streams far beyond the former margin of a glacier and confined within the walls of a valley.